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NASA CR-66934

FINAL REPORT

TECHNICAL FEASIBILITY DEMONSTRATION MODEL OF ORBITING EXPERIMENT FOR STUDY OF EXTENDED WEIGHTLESSNESS

By J. M. Smith, R. B. Maine, et al.

Prepared Under Contract No. NAS 1-8200 by

Biotechnology
LOCKHEED MISSILES & SPACE COMPANY
Sunnyvale, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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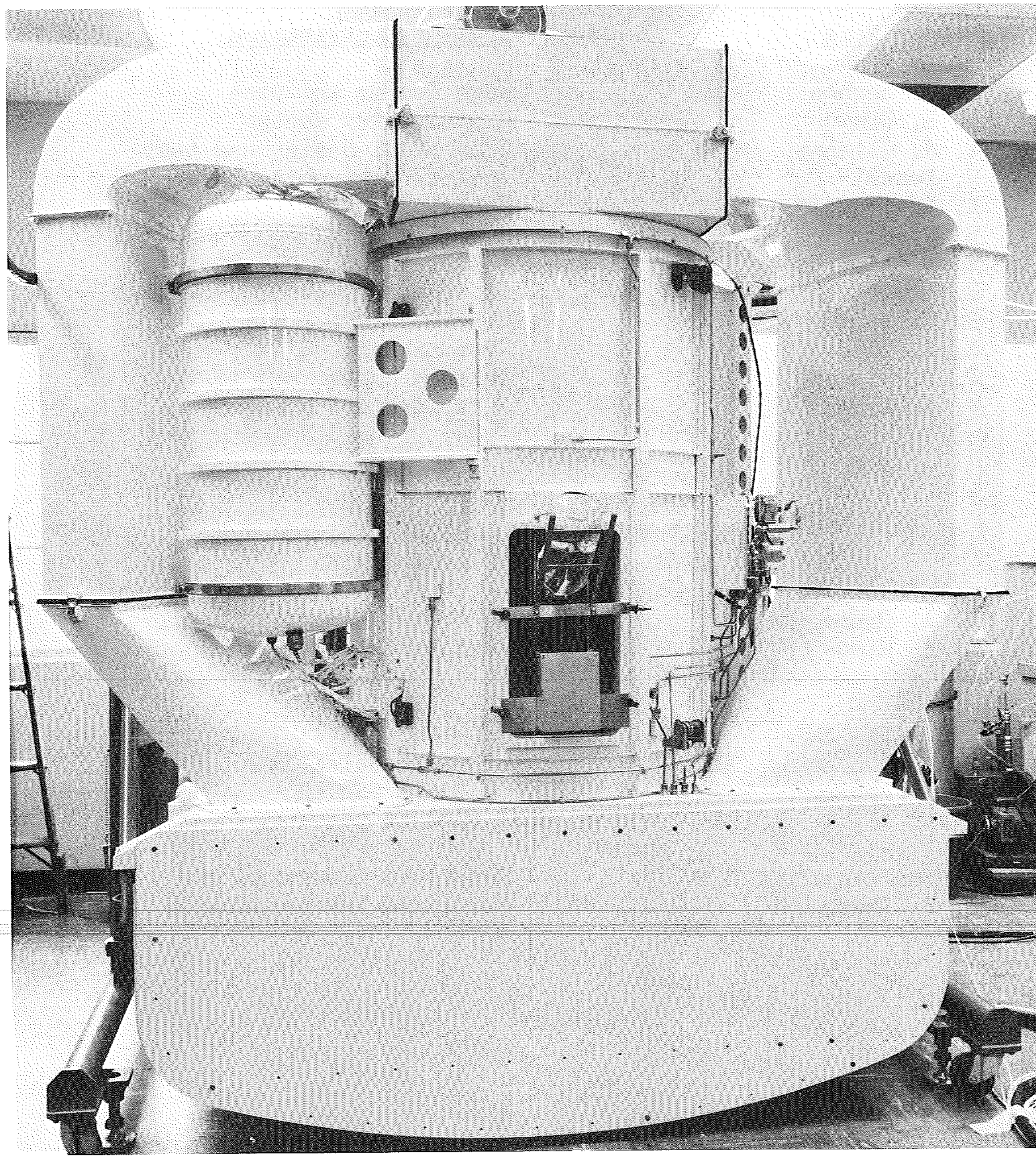

FRONTISPIECE: OPE Technical Feasibility Demonstration Model

ACKNOWLEDGMENTS

Major contributions to this report were made by the following persons:

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INTRODUCTION AND SUMMARY

The Orbiting Experiment for Study of Extended Weightlessness is under the direction of Dr. Walton L. Jones, M. D., Director of the Biotechnology and Human Research Division, Office of Advanced Research and Technology (OART), Headquarters, NASA. Mr. Warren Guild, Chief of the Space Flight Projects Branch, Special Programs Office, OART, is responsible for program direction in regard to spaceflight considerations of the program. The objectives of the program are to provide:

- Physiological and psychological data applicable to extended manned space flights, particularly in regard to possible subtle effects of extended weightlessness
- Scaling factors for long-term life support requirements in the weightless environment
- Long-term life support component and system performance

To this end, the primary goal of the program is to place two primates in low-earth orbit for a period of six months to one year, and to recover them alive at the end of the mission. Following this orbital exposure, the primates will be subjected to exhaustive ground-based laboratory examination and observation to obtain further data on weightlessness effects.

The baseline Orbiting Primate Experiment (OPE) is planned to be carried as part of an independent spacecraft which is completely self-sustaining during the period between orbit injection and animal retrieval. In this baseline mission, one of the Apollo Applications Program (AAP) flights is assumed to provide the launch vehicle. At the end of the six to twelve months mission duration, the experimental animals will be returned to earth by the Apollo Command Module of a subsequent AAP flight. The experimental animals to be used are two rhesus (Macaca mulatta) monkeys, each approximately 13 pounds in weight.

The following alternate mission option groups have also been explored and found to be feasible for the conduct of the experiment:

1. Experiment docked to the Orbital Workshop (OWS) Multiple Docking Adapter (MDA)
2. Experiment installed in the OWS Multiple Docking Adapter/ Air Lock Module (MDA/AM)
3. Experiment installed within the OWS S-IV-B Stage
4. Use of unmanned Titan launch vehicles to place the payload into orbit where it would either go into solo orbit, dock to the MDA, or station-keep with the OWS.

5. Use of unmanned Titan or Saturn launch vehicles to place refurbished and modified Apollo Command Modules, containing the experiment, into orbit.

In options 1, 2 and 3, the primates are returned to earth in a manned Apollo Command Module. In option 4, the recovery capability is extended to include the use of modified Discoverer re-entry capsules. In option 5, the refurbished and modified Apollo Command Module is used for primate recovery. These mission options are described in greater detail in Ref. (1) and (2). Options 4 and 5 described above are the same as Modes A, B, C, and D in Ref. (2).

Since the payload conceptual design for all mission modes is the same, and the payload is the pacing development item, the Lockheed Missiles & Space Company was directed to undertake the development of a payload Technical Feasibility Demonstration Model (TFDM) as the major effort under NASA Contract NAS 1-8200.

The TFDM consists basically of a cylindrical cage 34" in diameter and 48" high equipped with automatic feeding and watering systems, and a passive waste management system using a phosphoric acid impregnation to absorb ammonia. Two cage airflow levels are provided: 200 cfm for normal operation and 2000 cfm for periodic cage cleaning. With the higher flow rate a greater assurance is provided that the primate's waste products will be transported to the passive waste management system. Oxygen, CO_2, H_2O and trace contaminants are controlled by a fixed bleed of 12 cfm into and out of the cage. Total pressure in the cage is approximately 14.7 psia and temperature control is $\pm 1^{\circ}F$. The Lockheed TFDM is built to house one primate and to interface with the Northrop TFDM, which also contains one primate. The two units are interfaced at a 10" wide, 18" high, social window having 1/4" vertical bars to allow the primates to have physical contact but not access to each other's cage.

The primate's food is pelleted Purina Monkey Chow; the water supply is filtered, heat-sterilized, tap water.

The primate operates behavioral task levers and an exercise device during a 14-hour work period; he is rewarded with food or water for correct responses. Manual override capability is provided to allow feeding and watering the primate, regardless of his performance, if this is desired or required.

Illumination in the cage is simulated daylight for the 14-hour work period, with an intensity adjustable between 15-35 ft candles at the cage floor.

Instrumentation is provided to record ECG and body temperature data telemetered from the primate, body mass, and primate activity and vocalization events. High resolution video coverage is provided from a camera mounted in the top of the cage. This camera has pan, tilt and zoom capabilities. A fixed, side-mounted, wide-angle camera is also provided.

Provisions are made to automatically retrieve the primate from the large (34" diameter) cage into a small (14" diameter) retrieval canister. This is accomplished by automatically rolling up a thin stainless steel liner within the large cage until it matches the diameter and location of the retrieval canister opening. A pneumatic actuator then gently elevates the primate into the canister for retrieval at the end of the mission. In this system, provisions are made to handle an expired or disabled primate.

While the hardware was not meant for flight use, careful attention was given to two areas especially vital to such hardware: (1) corrosion protection and (2) fire prevention. In the latter instance, the NASA Non-Metallic Materials Design Handbook was used as a guide in selection of materials of construction, and flammability tests were conducted on suspect materials. In addition, a quick-release animal escape port was provided. National Sanitation Foundation Standards were used as guides in the design of the hardware. Cracks and crevices were minimized by welding and potting, and the equipment generally designed for ease of cleaning.

During the early design phase of the program, a number of critical hardware elements were identified for which development tests were required either to verify design assumptions or to provide additional information for final design. These tests covered the areas of (1) the load required to force the piston into the retrieval canister, (2) cage liner retraction mechanism, (3) feeder mechanism, (4) food tablet vibration, (5) behavioral task lever operation, (6) television system and lens selection, and (7) biomedical monitoring system, including antenna array development.

The food tablet vibration test was for the purpose of ensuring that the tablets themselves could withstand the launch vibration environment. Due to the relatively hard coating on the tablets and the tablet hardness itself, the tablets survived vibration testing without significant deterioration. The other development tests generally exposed a few basic problems and provided an opportunity to evaluate various corrective approaches before committing to final design. This effort proved to be highly successful in that relatively few problems were encountered with the equipment in its final configuration.

Following equipment fabrication, a number of system tests were conducted to verify the operability of critical systems prior to acceptance testing. The following system tests were conducted:

1. Primate/equipment interface test to verify the compatibility of the primate with the cage, cage liner, social window, behavioral task panel and side TV port.

2. Mass measurement system test to determine the accuracy of measurement using calibrated weights as a basis.

3. Feeder vibration test, wherein a fully loaded feeder was vibration-tested in all three axes in accordance with expected environmental conditions at the feeder during a Saturn 1B launch.

4. Immediately following vibration testing, an accelerated life test of the feeder was conducted to demonstrate the capability of the feeder to dispense a one-year supply of tablets.

5. An accelerated life test of the watering system to demonstrate its capability to dispense a one-year supply of water.

6. Illumination and TV demonstration to evaluate general performance and to determine the effects of illumination level on the quality of the video picture.

7. Electromagnetic interference (EMI) testing of the biomedical and activity monitoring systems to determine their susceptibility to EMI.

8. Behavioral programmer demonstration to evaluate the capability of the behavioral programmer to function satisfactorily while connected to all of its interfacing equipment, e.g., task lever assembly, exerciser, feeder, waterer, and noxious stimulus system.

Results of the system tests showed that the equipment was compatible with the primate, that the feeder and water systems (after some modifications) would operate satisfactorily for long-term runs, that the feeder could withstand the Saturn 1B launch vibration exposure without any detrimental effects, that the illumination and TV viewing systems were fully adequate, that the behavioral programmer (after some modifications) was compatible with its interfacing equipment, that the biomedical monitoring system demonstrated some sensitivity to electromagnetic interference and that the mass measurement system, as initially installed, did not provide the requisite accuracy. The magnetic activity monitor was found to be activated by solenoid and switch operation; consequently, this system was not used. Activity monitoring is still possible, however, using the photocell and field strength systems.

After corrective actions based on the above results, an acceptance test was conducted at LMSC using the NAMI supplied primate. During this test, all systems were functioning except the ECG and temperature telemetry systems, and the magnetic and field-strength activity monitoring systems. Except for the interference problems with the magnetic activity monitor, noted above, this was in accordance with the contract requirements which called for implanted primate subjects to be used only for the NAMI tests.

During the acceptance test, the primate learned his behavioral tasks quickly and achieved considerable proficiency. Two adverse primate reactions were initially noted: (1) a reluctance to use the telescoping exercise device and (2) lack of the desired response to the avoidance task (entrance into the retrieval canister). As the test proceeded, item 2 was cleared up completely and some improvement was noted in item 1.

The mass measurement system did not initially perform within the desired 1% accuracy, but modifications were made during the acceptance test which corrected this problem. The primate presence sensor was intermittent.

No problems were encountered during this two-week test period with the feeder, waterer, air circulation and temperature control, waste management, video, or behavioral equipment. Upon retrieval of the primate at the conclusion of the test, one of the cage liner positioning tethers malfunctioned but cage rollup was successfully accomplished. The pneumatic actuator lifted the primate into the retrieval canister, but failed to effect a canister seal due to misalignment problems.

Prior to shipment of the hardware to NAMI, the following items were corrected and/or successfully demonstrated:

1. Fan ΔP switch inoperative. This was due to incorrect plumbing of the ΔP switch.

2. Replacement of the "calibrate" and "run" potentiometers on the mass measurement readout panel with higher quality hardware.

3. Installation and checkout of the animal core temperature readout system.

4. Installation of a sound attenuator and ΔP probe for the redundant 200 cfm fan.

5. Replacement of the cage liner tether which failed during the test and correction of the cause of failure (absence of a ball on the mounting end of the tether).

6. Photographing of the oscillograph readouts of all signals planned for transmission to the NAMI recorders.

7. Provide the necessary logic to have the exerciser cue lights alternate "on" and "off" as a function of desired handle stroke positions.

8. Demonstrate, with a primate, that the retrieval canister door will latch into the closed position.

9. Demonstrate that the modifications to the "primate in canister" indicator operate satisfactorily.

10. Calibrate and install markings on the exerciser position meter.

11. Replace the ECS exhaust ducting with self-extinguishing material.

Following delivery of the Lockheed TFDM to the Naval Aerospace Medical Institute, Pensacola, Florida, the primate capsule was located in an acoustic and RF attenuating room, and connected to the Northrop TFDM at the social-window interface. The control console was connected to the NASA/NAMI recording equipment. The water system was gas-sterilized and charged with local tap water which had been filtered, sterilized and treated with sodium hypochlorite to achieve a free chlorine residual of approximately 0.5 ppm.

The primate (2Z4) entered the Lockheed capsule on Friday, 24 October and the test was successfully concluded on 18 December 1969.

A summary of major test results is shown below:

1. Cage temperature remained within $\pm$ 1°F of the 77°F set point.

2. Water aliquots were checked before and after the test with the following results: 2.880 ml (before) and 2.879 ml (after).

3. Primate health after the test was good and he had gained about 5% in body weight during the test. Correlation between animal weight and mass measurement system indication: 7.365 Kg actual vs 7.4 Kg as indicated by the mass measurement system.

4. Primate major locomotion activity was primarily from the floor area to the retrieval canister and back.

5. Hair loss on the primate was less than it appeared to be via video viewing. New hair growth over surgical areas was approximately 1" long.

6. The primate did a good deal of picking and chewing on the cage and apparatus; he was able to pick out one rubber seal used in the retrieval canister.

7. The primate operated the feeding and watering lip switches almost exclusively with his mouth.

8. There was an undesirably large fecal waste buildup in the retrieval piston area.

9. The exercise unit did not appear to be consistent in regard to the operating force required, and the force required is larger than desired.

10. During the test the top viewing TV camera did not provide the quality observed prior to delivery to NAMI. This problem was recognized early in the test and a decision was made to proceed, using the combined top and side TV views for animal coverage. Following this test, the

entire camera system was returned to the manufacturer for complete servicing.

11. The capsule exhaust-gas odor level was objectionable to test personnel but this had no apparent effect on the primate. Inclusion of the ECS charcoal in the waste management system wicks rather than in the ECS process loop is indicated.

*12. Biological tests on the water supply using the Standard Millipore Filter Method for the identification of coliform group organisms were negative throughout the test. Blood Agar plate samples were positive for growth of the following organisms on the dates indicated:

10-16-69	Bacillus spp.
10-23-69	Bacillus spp.
10-30-69	Unidentified gram neg. rods
11-6-69	Staph, Streptomyces and gram neg. rod
11-14-69	Staph, and Streptomyces
11-24-69	Gram neg. rod, TNTC
12-1-69	Gram neg. rod, TNTC; Identified as Pseudomonos spp.
12-8-69	Pseudomonos spp. TNTC
12-15-69	Pseudomonos spp. TNTC
12-18-69	Pseudomonos spp.

Conclusions resulting from this program effort are as follows:

- Significant problems exist with electromagnetic noise interference in the biotelemetry system.
- The water system becomes contaminated with a variety of organisms, probably by growth from the lip device back to the water tank. This contamination was not sufficient, however, to cause difficulties to the animal or to the water system hardware.
- The waste management system absorbed urine satisfactorily. Some fecal waste build-up was observed in the retrieval piston area but it did not endanger the primate or interfere with system operation.
- The ammonia concentration in the capsule was held below the allowable concentration but the odor level in the capsule was higher than anticipated. This did not appear to affect the primate.

*All data from Naval Air Station, Pensacola, Florida

- Noise from the TV pan, tilt and zoom system was distracting to the animal and made it impossible to change the viewing angle and/or magnification without evoking a response from the primate.

- The cage rollup and retrieval system was demonstrated and proved satisfactory, including the retrieval piston door lockup in the retrieval canister.

- Floor louver spacing proved satisfactory, allowing fecal material to pass into the collection container.

- The exercise unit did not appear to be consistent in regard to the operating force required, and the force required is larger than desired.

- The feeder, using a bulk food storage concept, proved to be very reliable.

- The water system tankage, valving, and aliquot accumulators proved to be reliable and consistent in the aliquots of water dispensed.

- The "primate in canister" sensor did not prove to be reliable due to the fact that some animal positions in the canister did not provide a signal.

- The animal vocalization system performed below the design goal due to start-up inertia in the tape recorder and acoustic interference.

- The 200 cfm fan noise was higher than desired.

- Protective screens over the TV viewing ports interfered somewhat with TV viewing.

The following recommendations are made for TFDM system improvement:

- Determine the sources of noise appearing in the biotelemetry signals at the NAMI test site. Determine at what points in the biotelemetry system the noise is entering the system and filter the noise at that point. Consider moving the biotelemetry receivers from the control console to the TFDM structure where they would be closer to the receiving antenna.

- Consider high temperature water storage to prevent microorganism growth and/or UV or chemical treatment of water in the delivery line as close to the lip device as possible.

- Include the environmental control system charcoal in the waste management system wicking to reduce the odor level in the cage.

- Reduce the noise in TV pan and tilt system by the use of fiber gears and rubber shock isolation mounting of the complete assembly and the motor drive system.

- Rework the exerciser unit using ground tubes with very close tolerance control. Replace pulleys and belts with precision gears. Design special constant-force spring to overcome tube mass and system friction.

- Replace existing "primate in canister" sensor with a minimum of four photo cells at various levels in the retrieval canister at 45° clocking.

- In the animal vocalization system use a continuous running endless tape for recordings and transfer primate vocalizations to a second recorder which would operate only when required. In this way, the first sound emitted would be recorded. Reposition the pickup microphone away from the existing fans and nearer to the behavioral task panel. Lower fan background noise by using squirrel-cage fans in the 200 cfm air loop. This would lower the sound level to approximately 75 db, however, about twice the electrical power is required.

It is further recommended that the existing bulk storage feeder be either flown onboard a zero-g aircraft or be tested in the inverted position under one-g conditions to achieve greater confidence in the zero-gravity performance of this system. It is also recommended that a model of the waste management system be flown on board a zero-g aircraft for performance measurements in the zero-g environment.

The results of this program fully support the fact that the design and fabrication of hardware to support long-duration orbital testing of unrestrained primates is possible within the existing state-of-the-art.

TECHNICAL FEASIBILITY DEMONSTRATION MODEL
REQUIREMENTS AND GUIDELINES

The requirements for the TFDM are, unless otherwise specified, the same as those for the flight payload. The major requirements based on the conceptual design study reported in Ref. (1), are listed below for the LMSC TFDM.

Requirements

Primate	One 6 Kg male rhesus (Macaca mulatta)
Mission Duration	6 months to one year
Cage Dimensions	34" diameter 48" height
Social Window	10" width 18" height 3 - 1/4" vertical bars on 2 1/2" centers
Atmosphere	
Pressure	Ambient (approximately 14.7 psia)
Temperature	$77 \pm 1^{o}F$ - Adjustable to 70 to $80^{o}F$
Humidity	Ambient
Oxygen concentration	Ambient
CO_2 concentration	Ambient
NH_3 concentration	3.5 mg/m^3 maximum
Other Trace Contaminants	0.1 of Industrial Threshold Limit Values
Air Velocity in cage	30 fpm average
Bleed flow	12 cfm
Food	
Amount	85,000 0.6 gm tablets
Type	Pelleted Purina Monkey Chow
Dispenser performance	0.75 sec delivery time 5 sec recycle time

Water	
Amount	385 lbs minimum
Type	Filtered, heat sterilized, tap water
Microbiological level	< 10 bacteria /ml
Dispenser performance	0.75 sec delivery time 5 sec recycle time 3 cc/actuation (adjustable from 1-5 cc/actuation)
Illumination	Simulated daylight 15-35 ft candles at cage floor (day cycle) 0.05 - 0.2 ft candles at cage floor (night cycle) 14 hr day, 10 hr night
Date Requirements	
Biomedical	ECG Temperature Mass
Behavioral	Activity Vocalization Task Performance (timing, vigilance, interlock, exercise, and avoidance)
General	Food tablets - number delivered Water - cc/delivered TV coverage Cage temperature Bleed flow in and out of cage
Retrieval	Automatic recovery of animal from cage into retrieval canister

Guidelines

In addition to the above requirements, the following guidelines were adopted for the LMSC TFDM:

Corrosion	
Dissimilar Metals Protection	LMSC engineering design handbook
Anodize Aluminum	LAC 0494 or 0445

Guidelines (Cont.)

Primer Epoxy Polymide	MIL-P-27316
Finish Coat Epoxy Enamel	LAC 37-4037

Fire

Used Non-Metallic Materials Design Handbook, MSC-NA-D-68-1, as a guide
Conducted flammability tests on suspect materials
Used Durez Hetron 92 or 92-T resin in majority of non-metallic parts
Fuse/circuit-breaker protection on all vital circuits
Quick-release animal escape ports
Fire extinguisher to be available at the Naval Aerospace Medical Institute (NAMI)

Sanitation

Used National Sanitation Foundation Standards as a guide
Minimized cracks and crevices by welding and potting
Designed for ease of cleaning

TECHNICAL FEASIBILITY DEMONSTRATION MODEL DESCRIPTION

The TFDM comprises all subsystems of the experiment which interface with the animal except for zero gravity mass measurement, and atmosphere regeneration. An earth-gravity load-cell mass measurement subsystem has been incorporated in lieu of the proposed flight system, based on radiation attenuation. Atmosphere regeneration is achieved by bleeding a portion of the circulating air stream from the cage and replenishing the same amount from the test laboratory ambient atmosphere. In all other aspects, the TFDM reflects those concepts derived during the conceptual study, as reported in CR 66520. In this section, each of the TFDM's major elements are described.

TFDM Mechanical Assembly

The TFDM Mechanical Assembly is the residence of the primate test subject. The cage subsystem, which is a vertical cylinder 34 inches in diameter and 48 inches high, contains fans, lights, TV, microphone, loud speaker, retrieval canister, and exerciser in the ceiling; retrieval actuator, mass measurement load cells, louvers, and noxious stimulus jets in the floor; and food and water dispensers, TV, noxious stimulus jets, activity sensors, antennae, social window, and behavioral task panel in the wall. The wall is lined with a thin sheet of stainless steel which may be retracted forcing the primate to a position directly over the retrieval actuator and under the retrieval canister. The retrieval actuator then translates the primate into the retrieval canister. The canister is then detached, simulating a flight retrieval.

Located peripherally around the cage are the watering subsystem, feeder, liner retraction mechanism, air ducts, and pneumatic valve panel.

The cage and its appurtenances are supported by an aluminum structure which closely resembles the spacecraft design. This structure consists of an upper and a lower deck which connect with the upper and lower ends of the cage. Vertical beams also span the distance between these two decks. Suspended from the lower deck is the fiberglass waste management assembly. Four structural brackets on the lower deck are the primary hard support points for the TFDM mechanical assembly. Two hard points on the upper deck are used to eliminate swaying.

<u>Cage Subsystem</u>.- The cage subsystem provides the basic containment of the primate test subject. It also either provides support to, or interfaces with, every subsequent system which is to be discussed. The cage is a vertical aluminum tube 34 inches in inner diameter and 48 inches in height (See Fig. 1). The aluminum tube, which is 0.050 inches thick is stiffened

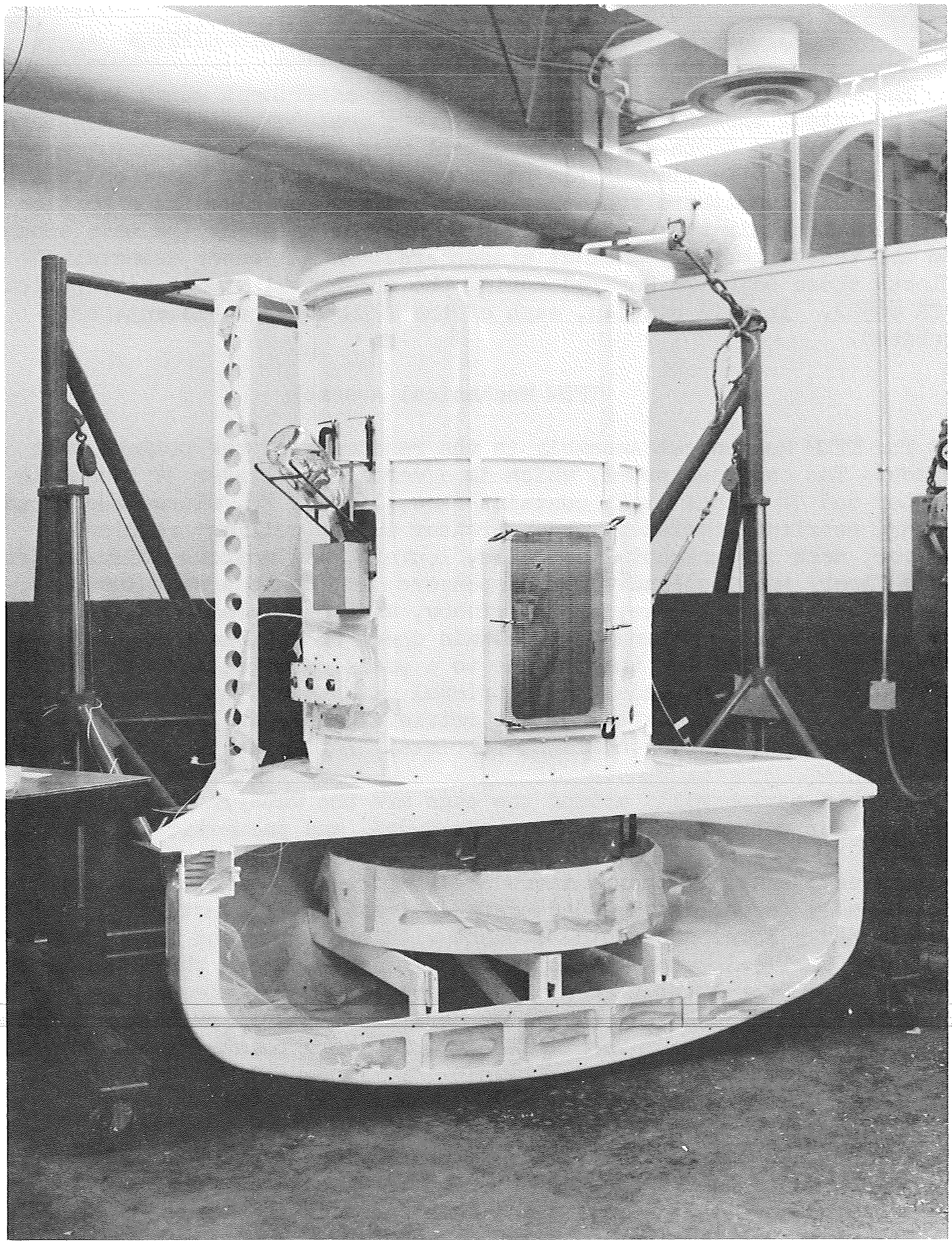


Figure 1 Cage Subsystem

by the addition of ten vertical longerons, or uprights, and three circumferential rings. The top and bottom rings of the cage are fastened to the basic structure.

A thin sheet (0.016 inches thick) of full hard AISI 301 stainless steel lines the inside curved surface of the cage. One end of the liner is led tangentially out of the cage through a vertical slit in the cage wall. This end is then wrapped around a 5-inch diameter vertical take-up spool. The other end of the liner is secured to the cage wall adjacent to the liner exit slit. By rotating the take-up spool, the liner is either retracted from or deployed into, the cage. The limits of its motion are controlled by a limit switch sensing perforations in the liner near the take-up spool. The function of the liner is to force the animal into a location directly over the retrieval actuator and under the retrieval canister. As the liner is retracted, its diameter diminishes and its center of curvature ultimately coincides with the vertical axis of motion of the retrieval actuator. This action sweeps the animal (dead or alive) directly over the retrieval actuator. Subsequent operation of the telescoping retrieval actuator pushes the animal vertically into the retrieval canister.

Numerous perforations of the liner permit accessories located on the cage wall to either penetrate into or view the cage interior. Penetrating items include the water and feeder lip devices and the three levers of the behavioral task panel.

Items which view the cage interior through perforations, but do not penetrate are:

Noxious stimulus air jets

Photocell and light source

Side-mounted television

Social panel

Exerciser cue lights

These perforations are so arranged that when the liner is fully retracted they have withdrawn from the cage. This negates the possibility of shearing an appendage during the vertical translation of the animal by the retrieval actuator. One exception to the above is a single noxious stimulus performation. However, its small size, 0.093 inch diameter, precludes any possibility of shearing action.

The perforations surrounding the protruding items (lip devices and behavioral task panel levers) are purposely elongated in the cage circumferential direction, and displaced eccentrically towards the fixed end of the liner. This is done to permit the liner to pull away from the protuberances without striking them. The perforation for the social panel is large (10 inches wide by 18 inches high). The frame for this perforation contains three 0.25 inch diameter vertical bars which prevent egress of the animal. Since the bars present an excellent purchase for the animal, a compressive preload in the liner is employed to prevent the animal from pulling the social panel away from the cage wall. This preload also prevents the animal from obtaining a fingernail hold between the liner and the cage wall at other liner perforations.

To maintain liner circularity in a one-g environment, and to ensure social panel bars not striking the protuberances, two tethers are installed which apply a constant, radially outward, force on the liner at approximately its mid-position (when deployed.) The tethers are powered by constant force spring motors which are mounted on the outside circumference of the cage. Miscellaneous guide rollers complete the basic liner installation. The take-up drum is mounted in two self-aligning spherical bearings, the bottom one taking thrust loading. The bottom bearing may be adjusted radially or vertically to permit the liner to wrap up smoothly. The top bearing is fixed, and the shaft which rides in it is keyed to an adjustable slip clutch. The clutch is adjusted for approximately 500 in-lb of torque to protect mechanical components from overload. The clutch is driven by a chain and sprocket set which is splined to a 28 VDC gear motor. In case the gearmotor fails, the chain may be disengaged by removal of a master link. The liner may then be manually operated. A removable air-tight cover is installed over the exit slit and the take-up drum to prevent cage atmosphere from leaking.

The floor assembly is the lower boundary of the cage. It also provides a mounting point for the one-g mass measurement load cells, some of the noxious stimuli jets, the retrieval actuator, and the floor movement actuators.

To prevent pinching of the animal between the floor bars and the liner, as it is being retracted, louvers were substituted for the bars. A majority of the time, the louvers are in the open or streamlined position. Just prior to liner retraction, the louvers are rotated to produce a flat floor. This removes all the possible shearing edges and permits "clean sweeping" of the animal across the floor. To insure that the animal does not become pinched in the floor by the louvers, (especially in the case of a deceased animal) the floor (excepting the retrieval piston and two small sectors adjacent to it) is mechanized to impart a momentum to the animal in an upward direction. This momentum carries the animal away from the floor and (in weightlessness) provides sufficient time of flight to operate the louvers. The floor comes to a rest at a position 0.125 inch from the bottom of the liner. A truss below the movable floor assembly provides support for the four noxious stimulus air jets, the four floor translation pneumatic actuators, and the retrieval actuator.

The 26 louvers are mounted in a carrier ring with hinge pins which may be removed by pressing them on through. Thirteen of the louvers on each side are linked together with a common operating link. Each link has a separate single-acting pneumatic actuator. The two actuators operate simultaneously, when pressurant is admitted, but in opposite directions. Hence, all louvers operate upward in an outboard direction. The limits of louver motion are provided by adjusting (1) the length of the actuator push rod and/or (2) the actuator stroke. The actuator returns the louvers to the streamlined condition by a self-contained spring whenever the pressurant is removed and the port opened to exhaust to atmosphere. Although the animal may be able to overcome the spring return momentarily, it is not damaging to the floor, nor could it be sustained for any appreciable length of time.

The louver carrier ring is supported by four vertically arranged pneumatic actuators. These actuators operate simultaneously to provide the upward momentum to the animal. These translation actuators are also single acting with spring return. They cause the floor to move upward two inches whenever pressurant is admitted. The stroke of these cylinders is not adjustable, but the push rod length is. This permits alignment of the floor. The stationary housings of the translation actuators are mounted in the aforementioned truss. Again, the animal can momentarily overcome the return springs, but would soon tire if a sustained attempt were made.

The truss also provides support to the retrieval actuator. This actuator pushes a piston, with the animal on top, up through the retracted cage liner. Near the end of the stroke of the retrieval actuator a solenoid-operated stop is installed. The stop must be energized to retract it. If the stop is retracted, the retrieval actuator may then proceed further until the retrieval piston latches into the retrieval canister. At this point, a shear pin breaks in the retrieval actuator permitting the actuator to retract leaving the retrieval piston latched into the retrieval canister. The retraction occurs, when the pressurant is removed, by action of two self-contained long-stroke constant-force spring motors. The shear pin may be replaced by (1) removing the retrieval canister, (2) removing the retrieval piston from the retrieval canister, (3) extending the actuator to full stroke, (4) disassembling the detached portion of the retrieval actuator from the retrieval piston, (5) re-engaging the actuator parts, (8) inserting a new shear pin, (9) installing the shear pin retaining screw, and (10) reassembling the retrieval piston on the end of the retrieval actuator.

The entire floor assembly is carried on three load cells which bear on non-moving portions of the underneath floor truss.

The roof assembly provides a mounting and interface area for the following systems or components:

1. Retrieval canister

2. Temperature sensor

3. Television camera

4. 200 cfm air circulation inlet

5. 2000 cfm air circulation inlet

6. Illumination

7. Exerciser

8. Microphone

9. Loudspeaker

10 12 cfm air circulation inlet

The roof structure is basically two circular plates separated 1.805 inch by a ring, and other internal spacers. It functions as a plenum with air entering at discrete points through the top plate then discharging uniformly through numerous small holes in the bottom plate. The exception is the 2000 cfm air flow which bypasses the plenum area and discharges directly into the cage area.

The retrieval canister attaches to the roof assembly with three twist-lock hasps. The canister is approximately 14 inches in inside diameter by 23 inches high. It is constructed of fiberglass with a transparent acrylic top cover and an aluminum latching and sealing ring at the bottom. Bonded to its cylindrical outside diameter are the animal presence sensor and the retrieval canister biotelemetry antenna. A carrying handle is included in the top cover plate.

Once the retrieval piston has latched into the bottom ring of the retrieval canister (forming an air tight seal), and the retrieval actuator shear pin has broken, the canister may be removed from the roof by releasing the three twist-lock hasps, and disconnecting the electrical connections. The animal can be removed from the canister by removing one shear pin from the top cover and sliding it sideways. Removal of the latched retrieval piston is accomplished by actuating each of the six pivots in turn and swinging up the catch to maintain them in the unlatched condition.

The noxious stimulus is a pulsating air jet. Thirteen of these jets are arranged as follows:

Quantity	Location	Direction of Air Blast
4	Floor	Straight Up
3	Lower cage wall	Inward, no inclination upward
3	Middle cage wall	Inward, 15^{o} inclination upward
3	Upper cage wall	Inward, 30^{o} inclination upward

Each level of jets are equally spaced within the level, but are staggered from level to level. This pattern provides for complete coverage of the cage volume permitting no sanctuary, save the retrieval canister, for the animal.

The pressurant is either nitrogen or air and is obtained from high pressure storage bottles which are located in the same general area as the control console. The entire flow of gas is regulated to 200 psig by a single-stage manual-set regulator. Portions of this flow are then subsequently regulated to 35 psig (for the water subsystem) and 100 psig (for the noxious stimulus jets).

Each of the three service pressure levels (200, 100, and 35 psig) has its own pressure relief valve. In addition, the master regulator has a built in relief valve. The failure mode of all regulators is to shut off (using upstream pressure for this purpose). In case of a master regulator failing open, each of the two relief valves, i.e., the regulator relief valve and the 200 psig service line relief valve, is capable of handling full bottle flow. In the event of failure of a subsequent station regulator on either the 35 psig or 100 psig service lines, the relief valve for either of those services is capable of handling the maximum flow of the master regulator. The normal gas supply bottle is provided with a rupture disc for over-pressure protection.

The three service lines run from the gas supply bottle to the TFDM mechanical assembly through hard tubing. A valve panel contains all the solenoid valves and flow restrictors required for operating (1) noxious stimuli, (2) floor translation actuators, (3) louver actuators, and (4) the retrieval actuator. Four 2-way 24 vdc solenoid valves (B20, B21, B22, and B23) control the gas to each of the four levels of noxious stimulus jets. Three 3-way 24 vdc solenoid valves (R1, R6 and R7) control the gas flow to and exhaust from the retrieval actuator, the floor translation actuators, and the louver actuators respectively. The flow into and out of these three actuator sets can be restricted by manual adjustment of variable orifice valves. A 3-way directional control valve (R5) permits selection of either a clear or restricted flow path to the floor translation and louver actuators.

Air Circulation and Temperature Control System

The air circulation and temperature control system maintains a continuous flow of temperature--controlled air at slightly above atmospheric pressure through the cage from top to bottom.

Air circulation.- A total of five fans are installed and operated as follows:

Fan	Operation
12 cfm #1	Continuous
12 cfm #2	Standby
200 cfm #1	Continuous
200 cfm #2	Standby
2000 cfm	Intermittent

Each fan has its own air flow check valve to prevent circulation through the parallel inoperative fan.

As shown in Figure 2, the operating 200 cfm fan draws its air supply from the return ducting plenum. The 200 cfm discharge flows through a two-flap counterbalanced check valve and into a cage roof plenum. The cage roof plenum discharges to the cage through a perforated plate, producing a distributed air flow of 30 ft/min average. Air flow out of the cage plenum also "washes" the fluorescent lamps and roof television window, discouraging adhesion of hair or other waste materials on these surfaces. Air temperature is sensed by a dual element sensor in this zone.

The air flow continues down the cage, passing through the floor louvers and the fecal container. After leaving the fecal container, the air undergoes a 180° turn, thereby separating moisture droplets, and enters two symmetrical return ducts. Electrical heating elements are located in each duct where thermal energy is added to the air stream as required. The air then returns to the ducting plenum and repeats the cycle.

In the event of failure of the operating 200 cfm fan, a differential pressure switch is actuated, causing an audio/visual alarm to operate as well as turning on a low differential pressure indicator light on the control panel. The standby unit may then be manually activated, which will automatically extinguish the low differential pressure indicator light on the control panel. The audio/visual alarm must then be reset manually. The air flow check valve on the standby unit will automatically open, and the other will close. Since the 200 cfm fan pressure rise is small (nominally 0.3 inches of water), the check valves must be adjusted for minimum operating force. This is accomplished in the gravity environment by moving counterweights nearer or farther from the pivot axis.

One 12 cfm fan operates continuously, drawing its air supply from the ambient laboratory atmosphere. Before the air reaches the fan, it is drawn past a pitot tube which is directly connected to an inflow differential pressure gage on the control console through two 50 foot lengths of plastic tubing. The incoming air then passes through a filter, an air flow check valve, and into the fan suction. The fan discharge flows through a butterfly

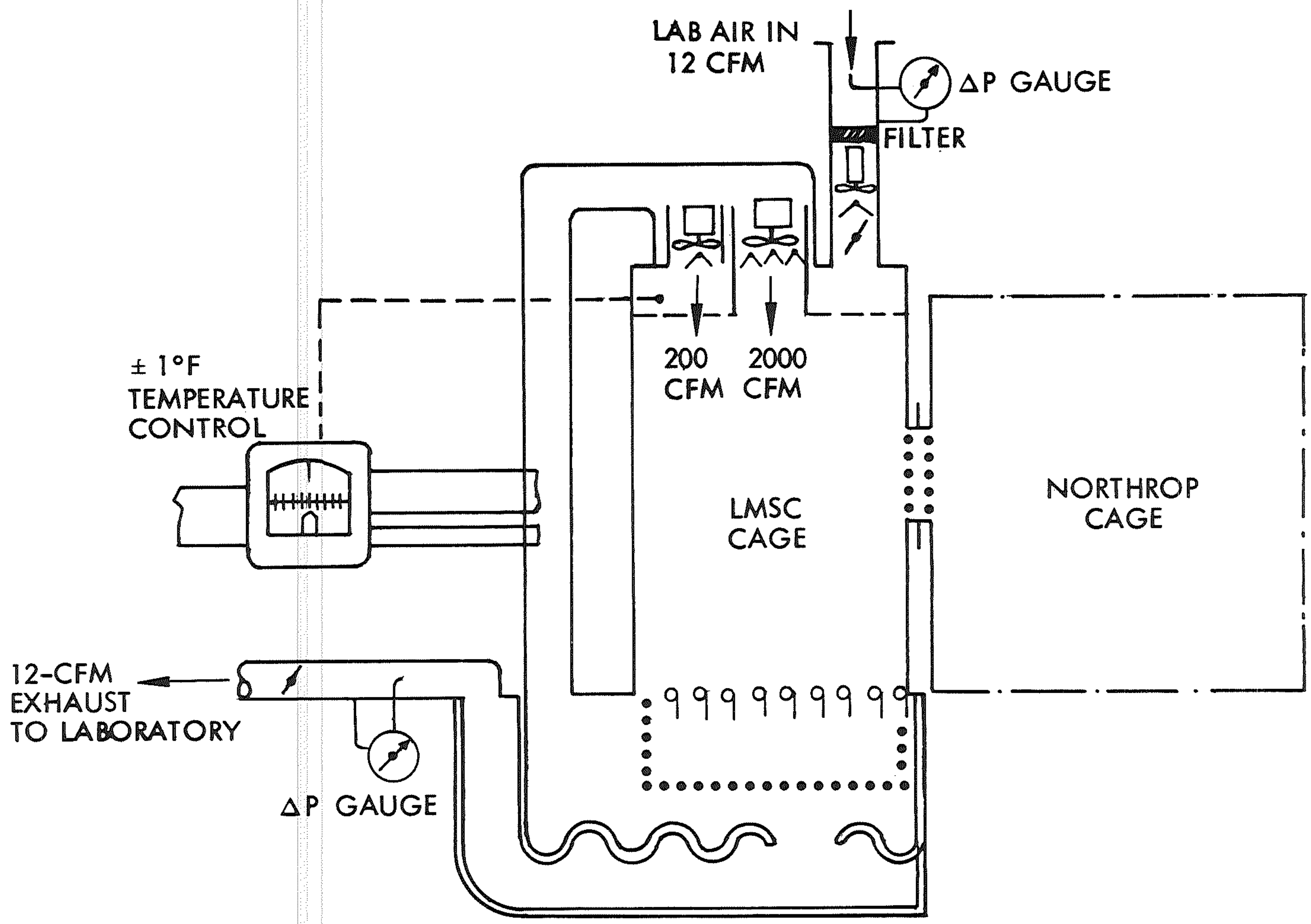


Figure 2 Air Circulation and Temperature Control Subsystem

valve which can be manually adjusted and locked to regulate inlet flow rate conditions. The air flow then passes into the cage roof plenum where it mixes with the discharge of the 200 cfm fan. Since the 12 cfm fan is related to atmospheric ambient pressure and all others merely recirculate air, the cage static pressure is determined by the pressure rise produced by this fan.

Below the fecal container is an opening in the wicking material through which 12 cfm is withdrawn from the TFDM mechanical assembly. Symmetrical headers collect this outflow and direct it past a second pitot tube and butterfly valve permitting it to be sensed and regulated. The outflow is ultimatedly directed to the laboratory exhaust system. This continuous 12 cfm purge removes excess moisture and contaminants from the cage atmosphere. In the event of failure of the operating 12 cfm fan, a differential pressure switch is actuated causing similar effects and alarms as was the case with the 200 cfm fan. Similar corrective action is taken.

Periodically, a large capacity 2000 cfm fan is operated to provide a strong blast of air to assist in cleansing the cage of waste materials. This fan is planned to operate in conjunction with the avoidance (AVD) task when the animal is located in the retrieval canister. However, it may be operated when desired by shifting to manual operation. This fan differs from the others in that after passing through an air flow check valve, it discharges directly into the cage (not into the cage roof plenum). The air flow recirculates through the cage and return ducting, taking the identical flow path as the 200 cfm air. Operation of this fan does not cause a change, other than transients, in cage static pressure because both its intake and discharge are inside the cage/ducting envelope.

Temperature Control.- The temperature control system consists of a console-mounted indicating temperature controller and electric heaters which are mounted in the air circulation ducts (See Fig. 3). The heaters are arranged in two heat range steps and each step is equally divided between the two ducts. In operation, cage air enters the ducts and flows past the heater elements. Heated air then passes into the roof plenum, where streams from both ducts are mixed, and finally passes through the inlet plenum and into the cage. The temperature sensing probe for the controller is located in the inlet plenum, close to the inlet of the cage.

The system is designed to hold the cage inlet air temperature at 70-80°F $\pm$ 1°F under ambient conditions of 65°F with a circulation rate of 200 cfm and a nominal make-up of air flow rate of 12 cfm. Physical and functional descriptions of both the controller and heaters are presented in the paragraphs which follow together with a description of integrated system operation.

The West Instrument Corp. Model JPTP-RT2-S65 solid state temperature controller was used. This unit incorporates dual time proportioning control bands, and operates in conjunction with a nickel resistance-bulb sensing unit. A time proportioning system with relay control was selected, in

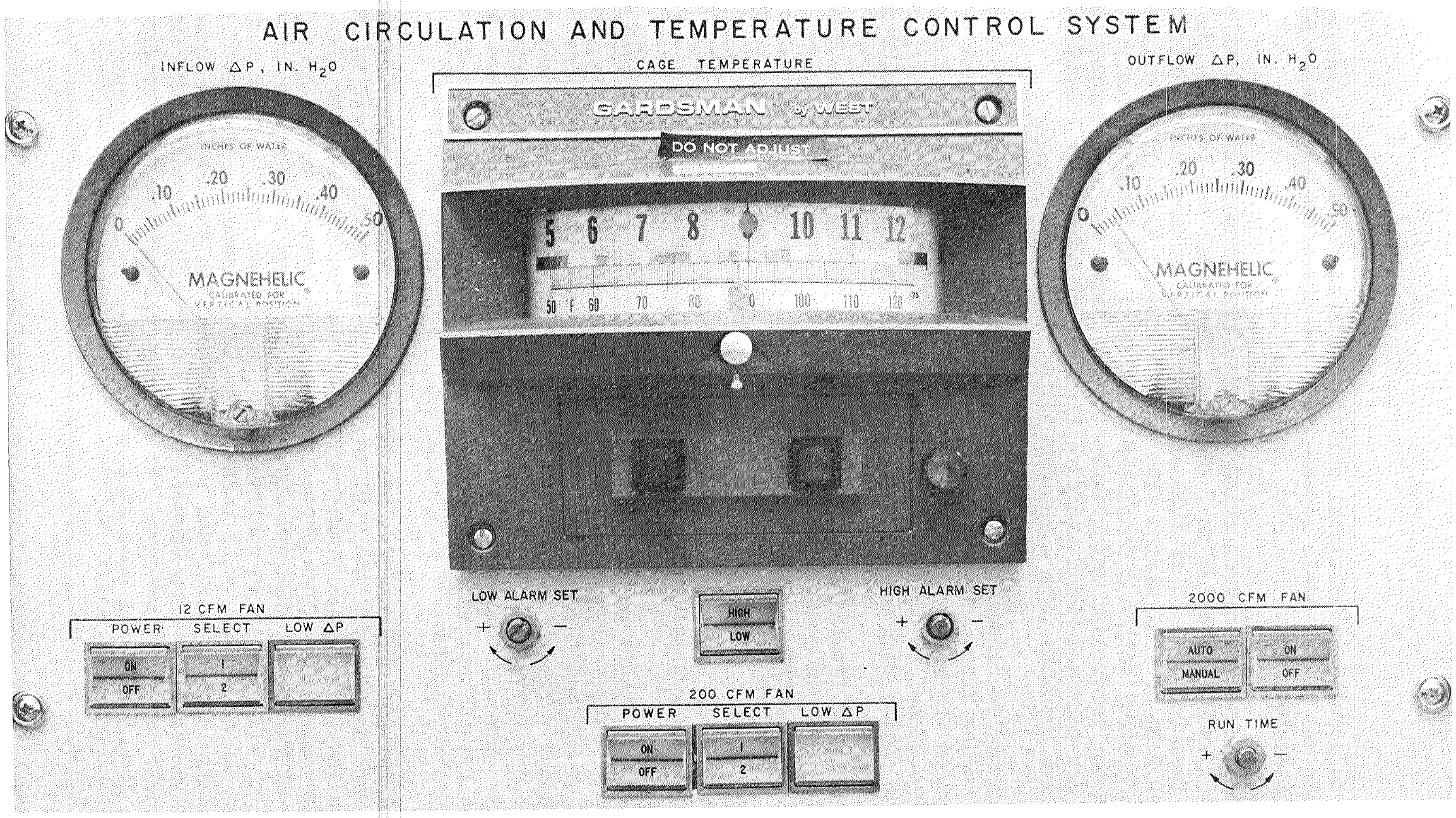


Figure 3 Air Circulation and Temperature Control Subsystem Panel

preference to a fully proportional silicon controlled rectifier system, as it allows the use of 400 cycle heater power and therefore, minimizes EMI problems inside the cage.

Operation on both control bands is fully time proportional, with total cycle time adjustable from 20 to 7 seconds. The upper and lower bands are adjustable from 0.5 to 1.5% of full scale, and are separated by a fixed dead band of 0.2% of full scale. The scale range of 50 to 125°F allows cage temperature control within a total band of 0.9°F. An integral meter is provided in the controller which shows the set point and cage temperatures, and lights are provided which indicate high or low heat range operation. The controller operates from a 120 vac 50/60 cycle power supply.

Temperature is sensed by a nickel resistance-bulb sensor, with activation power coming from a power supply in the controller. Dual bulbs are incorporated in the sensor to supply a signal to the controller, plus provide a temperature signal for recording. Output to the recorder from the sensor is a 0-5 vdc analog signal with voltage directly proportional to temperature.

The Chromalox finstrip heaters consist of a resistance wire element imbedded in a central core, with fins attached to the core to supply sufficient heat transfer surface area. Although rated at 1550 watts at 220 volts, the heaters are connected in series and operated on 120 v. This gives an effective power of about 100 watts per heater at a power density of 1.5 w/in^2. This low power density allows heater operation at only 100-150°F over cage air temperature and prevents transient overshoot.

As shown in Figure 4, two heaters are connected to the upper control band and four heaters are connected to the lower control band, thus providing heat steps of 200 and 400 watts. This hook-up minimizes power surges at low load conditions. The controller operates by sensing small variations in cage temperature and increasing or decreasing the power input to the heaters accordingly. The unit also anticipates rapid changes in temperature, by sensing the rate of change of temperature and adjusting to prevent operation outside the control band.

During periods of low load, the system operates on the upper control band only, and time proportions the applied power to the small heaters as required to maintain the proper cage temperature. As the required heating load increases, the cage temperature drops and the small heaters remain on a longer percentage of the cycle time and finally, if the cage temperature drops sufficiently, will remain on continuously. A further drop in cage temperature, below the dead band, will turn on the large heaters. The power to these heaters is also time proportioned in accordance with the load. A reduction in load would cause the cage temperature to rise slightly and would reverse the previously described process. If the cage temperature rises above the upper band high limit, all heat will be cut off.

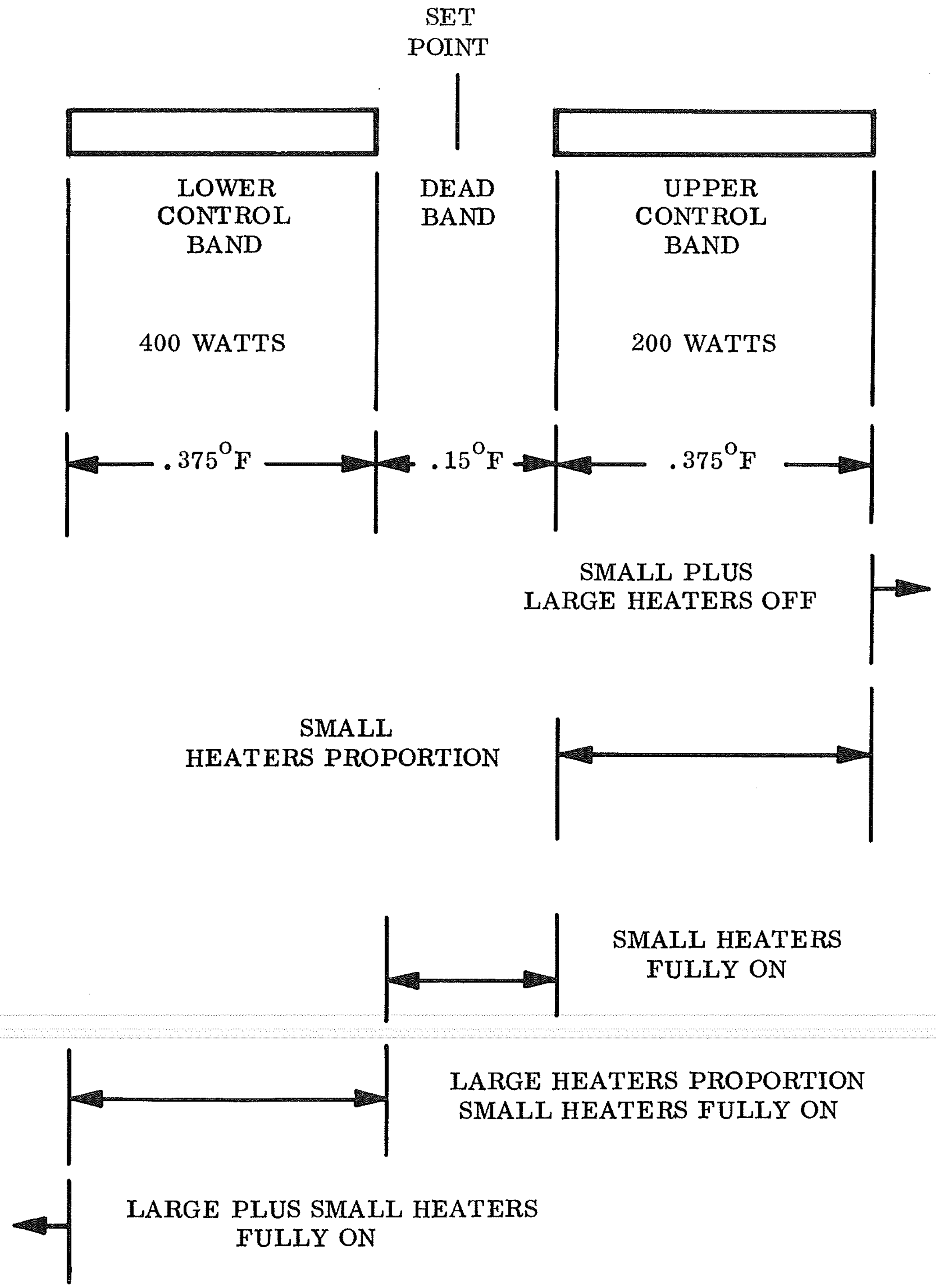


Figure 4 Operation of Temperature Control for Minimum Bandwidth Adjustment

Waste Management Subsystem

The waste management subsystem operates passively on the principle of phase separation of solids, liquids, and gases by utilizing air flow. The solids are trapped by passing all air flow through an 8 mesh stainless steel screen. The liquids are trapped by employing a 180° reversal of air flow to separate liquid droplets from the air stream. These droplets are deposited in wicking material where they are retained by capillary action. The wicking material is 4 lb/ft^3 heat-felted fiberglass impregnated with phosphoric acid.

The fiberglass wicking material is retained by means of (1) sewing it to stainless steel support screening and (2) covering it with a fiberglas net material. The phosphoric acid impregnation absorbs any ammonia which is generated from urea breakdown and in addition acts as a bactericide.

The collected solids are air-dried and soon stabilize in terms of bacteriological activity. The liquids which are entrapped in the wicking release water vapor to the air stream. These vapors eventually are carried off by the capsule air flow.

Intermittent operation of both the cage liner retraction mechanism and the 2000 cfm fan tend to dislodge and transport waste materials which failed to arrive at the waste management subsystem area by the normal method, especially under weightless conditions.

Feeder Subsystem

The feeder utilizes the volumetrically efficient concept of random bulk storage. The tablets are contained in a vertical cylindrical canister 18 inches in diameter by 39 inches high. Near the bottom of the canister is a lip device which protrudes into the cage when the feeder is mounted on the cage wall.

The tablets are contained between two conical surfaces whose apexes point upward and which nest together as the tablets are dispensed. The lower conical surface contains 72 cups evenly spaced around its perimeter which are slightly larger than a single tablet. The upper conical surface exerts a force toward the lower conical surface, compressing any tablets located between, by means of constant force spring motors. Thus, as the tablets are dispensed, the void is taken up, and a force is maintained which tends to keep the 72 cups filled. A pattern of resilient ridges bonded to the lower conical surface and on the vertical cylindrical wall tends to accentuate this effect. Below the lower conical surface is a mechanism which rams a tablet at a fixed index station out through the center of the lip device. This action takes place 3/4 of a second after the mechanism starts moving. The ram then retracts, and while retracted, the lower conical surface indexes one division. The whole cycle takes slightly less than 5 seconds. Control of timing between indexing and ramming is provided by a six-station Geneva mechanism and a face cam with extensive dwell time. The upper conical surface free-wheels inasmuch as friction allows. A vertical central fluted shaft maintains concentricity of the two cones.

Two redundant gear motors provide motive power to the mechanism through Sprague - type uni-directional drive clutches. In case of failure of one unit unit, the second may take over with no mechanical clutching or shifting required. Two sets of redundant SPDT microswitches provide (1) an actuation concurrent with maximum outbound motion of the ram, and (2) an actuation near completion of the cycle. The first set of microswitches provides a "tablet delivered" signal. The second set of microswitches cause the mechanism to shut down.

To fill the feeder, the hand hole cover plate on the upper dome is removed, and the upper conical pressure plate raised to its maximum height. The locking pin is then rotated one quarter turn to engage the detent groove. The hand hole cover plate on the pressure plate is then removed nad a flexible tube about 6 inches in diameter and 4 feet long is inserted through both hand holes so that it rests on the bottom conical surface. The feeder is then filled through this tube.

The electrical portion of the feeder assembly consists of two 208 v, 3Ø, 400 Hz, induction motors for driving the feeder mechanism and six microswitches for sensing lip switch activation, pellet dispensed, and cycle complete functions. It also contains a set of dual-filament lamp bulbs which serve as cue lights. The control console contains one logic card and the necessary control and display components.

During normal operation, the programmer provides an arming signal to the feeder logic card. This signal enables one input of a two input "and" gate. The other input is enabled by the lip switch activation signal. Thus, when the programmer arms the feeder logic and the primate activates the lip device, the system transfers to the cycling mode and the feeder motor starts.

Approximately 0.75 seconds later, the "pellet dispensed" microswitches are activated. This function advances the associated event counter one count, illuminates the appropriate monitor light, and gives a signal relay contact closure to the programmer, which removes the arming signal. The feeder will continue to operate through the cycle until the "cycle complete" microswitch resets the system logic. At this time the 400 Hz power is removed from the motor and a small DC current is applied to the windings for dynamic braking. The feeder system will remain in the reset mode until commanded "on" by the arming and lip device activation signals.

"Lip switch override" and "lip switch block" functions are incorporated in the feeder logic to provide manual control from the console.

Watering Subsystem

The required 385 pounds of water is stored in two identical spherical bladder tanks. A pressurant (either dry nitrogen or dry air) is admitted to the top of each tank. The subsystem operating pressure is 35 psig with a relief valve set at 50 psig. The subsystem proof pressure is 100 psig, and the burst pressure is 200 psig minimum. In addition, the entire subsystem may withstand complete evacuation without harm. The water system is evacuated and then filled with a 10% ethylene oxide-90% CO_2 sterilizing gas mixture. This mixture is held in the system for at least 12 hours. After evacuation of the sterilizing gas, the system is flushed with sterile water and filled with filtered and heat-sterilized tap water.

Each tank has a latching solenoid shut-off valve. A cross-connect latching solenoid valve permits either or both supply tanks to supply the dispensing system. These valves are located on a panel affixed to the ground handling dolly. Located on the same panel are water sampling ports. Each sampling port, which consists of a rubber septum, is covered with a pressure tight cap which prevents dirt from entering the septum area. It also provides a backup pressure tight barrier in case of septum failure. The septum will sustain a large number of needle penetrations, if the penetrations are widely spaced from each other. A record of septum penetration clock position should be maintained to preclude multiple penetrations in the same location. Water sampling must be done with sterile instruments and using a technique which will not introduce micro-organisms into the water system.

After passing through the sampling ports, the water flows through flexible hoses (to permit cage elevation) to a microbial filter and then to the dispensing valve panel. This panel is located on the cage wall and contains two parallel aliquot accumulators which alternately charge and discharge a measured amount of water as controlled by two 3-way valves. The metered water from either accumulator is then forced by a discharge spring through an adjustable flow control valve and another sampling port block. This sampling port permits withdrawal of samples as close as possible to the delivery end of the system. The flow control valve permits regulation of discharge velocity. After leaving the flow control valve, the water enters the lip device.

The lip device protrudes through the cage wall and constitutes the animal/waterer system interface. The animal places its mouth over the lip device and bites. As it bites, a lever actuates two redundant hermetically sealed SPDT microswitches. These switches cause a chain of events to occur which result in a measured amount of water to be delivered into the animal's mouth. Surrounding the lip device is a back-lighted round, translucent, white window which cues the animal to the fact that the system is ready for operation. If the animal removes its lips from the lip device during the delivery phase, the water will keep flowing until the metered amount is delivered.

The aliquot accumulator has provisions for adjusting the volume delivery from 1 to 5 cc per actuation. The discharge pressure may also be adjusted from 1.5 to 5 psig. When the volume adjustment has been made, the control panel knob should be adjusted to maintain the digital counter in synchronism with the accumulator. Figure 5 depicts the mechanism for adjustment of delivery volume and pressure.

The water system consists of three latching and two non-latching solenoid valves, two aliquot accumulators and a lip dispensing device as indicated in the above description. The system is controlled and actuated by three logic cards located in the life support rack of the control console.

Valves W1, W7 and W4 are the latching solenoid valves. They are operated from a 28 vdc source and controlled by 4 PDT switches of which 3 poles are alternate switching and 1 pole is momentary. This pole arrangement allows power to be applied to the valve only during actuation time. Valves W2 and W5 which are the non-latching solenoid valves, are also operated from a 28 vdc source but are controlled by a solid state switch located on the logic card.

The lip device arming signal from the programmer is gated with the lip device activation signal to yield a "water dump" signal. At this time power is applied to valve W2 (or W5 depending on which valve is enabled) which allows the water to flow from aliquot W3 to the lip device (W6 aliquot works in conjunction with valve W5). When the aliquot is empty, an internal switch feeds back an "empty" signal to the system logic. This signal is delayed by approximately 1.0 second to insure complete aliquot delivery. It then triggers the cc dispensed counter and resets the system logic. This function removes the power from valve W2 and allows aliquot W3 to refill. Another set of switches in the aliquot accumulator is used for monitoring purposes to indicate a full condition. The system is now reset and ready for another cycle.

Biomedical Monitoring Subsystem

The biomedical monitoring subsystem is shown in block diagram form in Figures 6, 7 and 8. This system performs a number of functions including the measurement of primate body temperature, ECG, activity, vocalization, and presence in the retrieval canister. The system also provides audio cues to the primate in response to signals from the behavioral programmer.

Temperature and ECG.- These parameters are broadcast from two separate transducer/transmitters surgically implanted within the animal's body. Receiving antennas in the cage wall and on the retrieval canister are coupled and the received signal is amplified and transmitted through coaxial cabling to the receivers (see Figure 9) in the control console.

The signals from two implanted transmitters must be received with adequate signal strength for a large percentage of time regardless of the

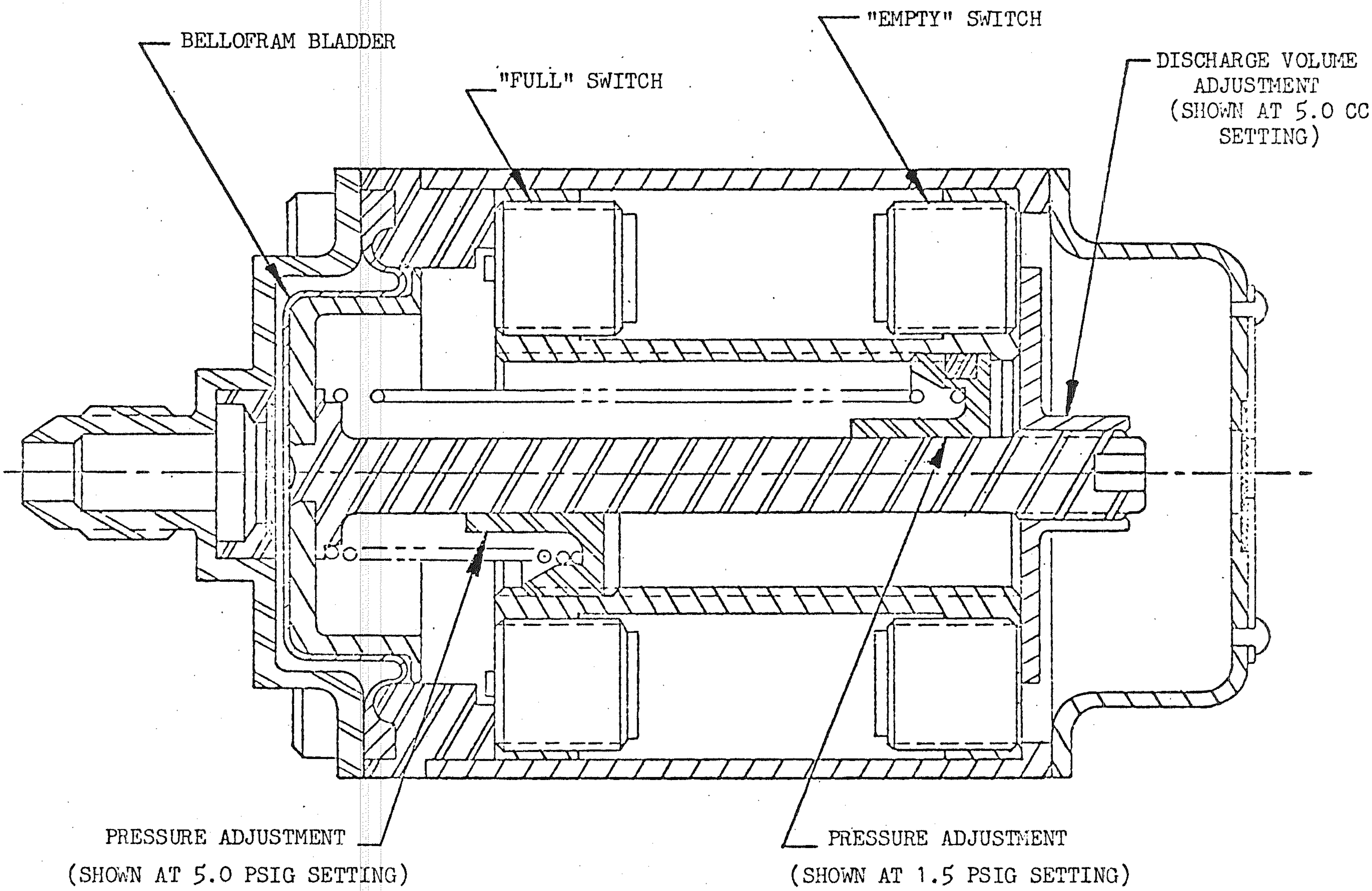


Figure 5 Accumulator Cross Section

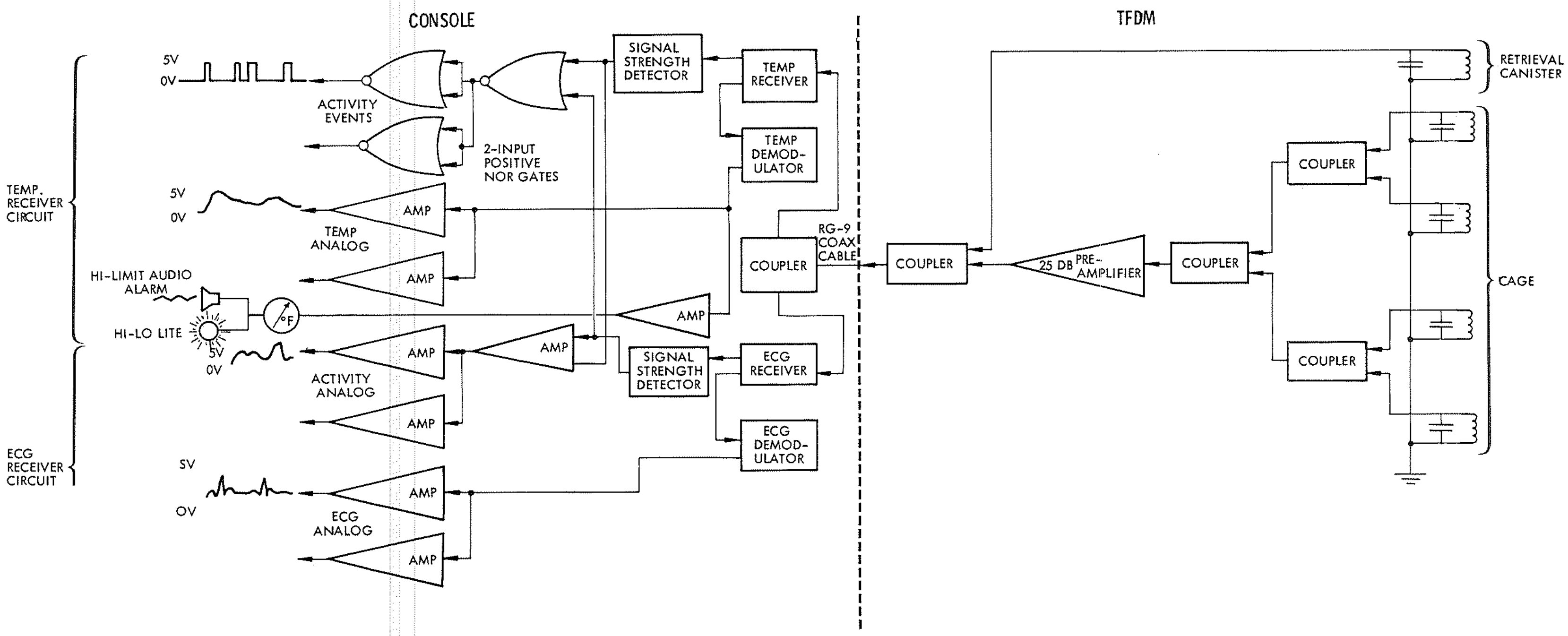


Figure 6 Biomonitoring System Block Diagram
(Temperature and ECG)

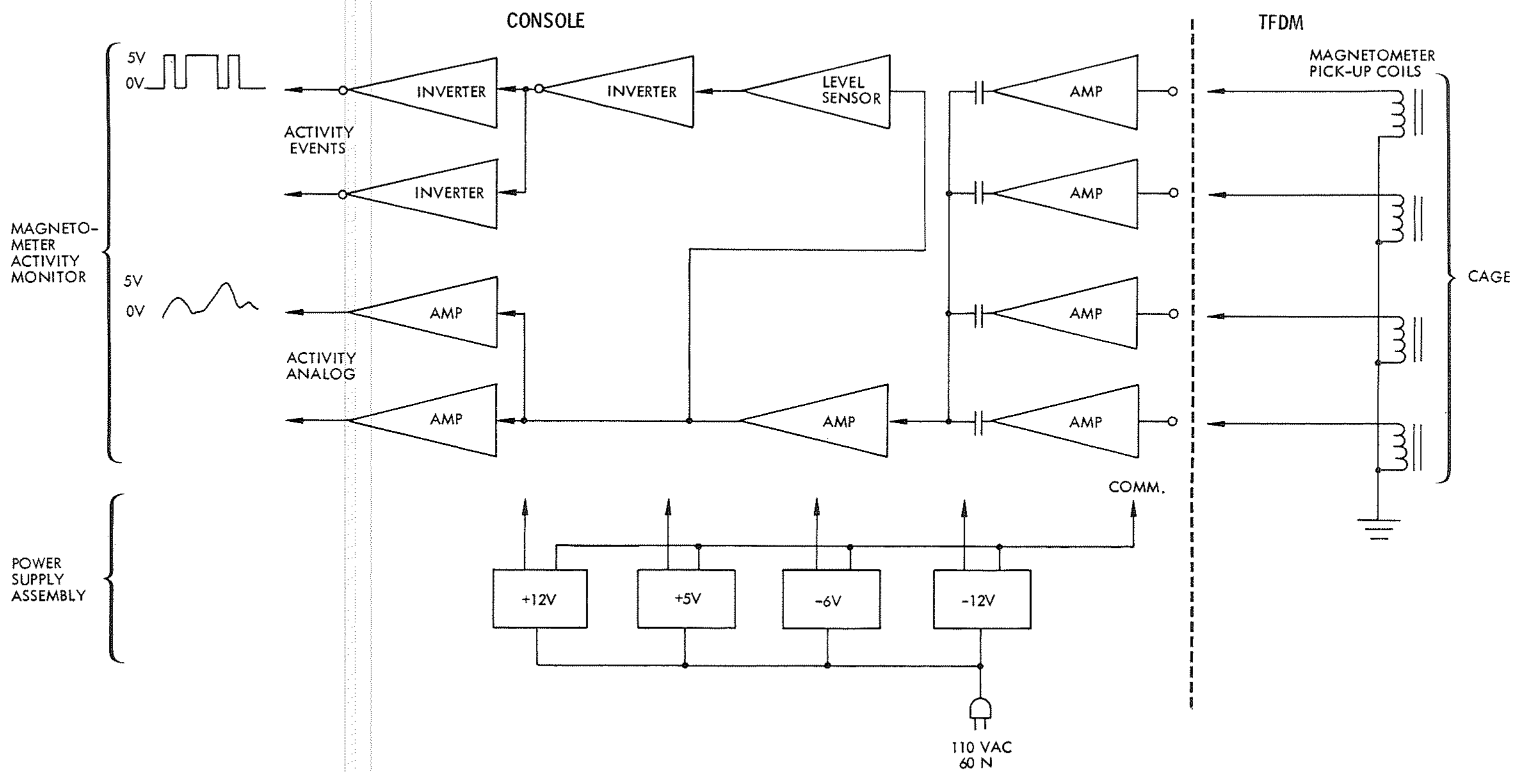


Figure 7 Biomonitoring Subsystem Block Diagram

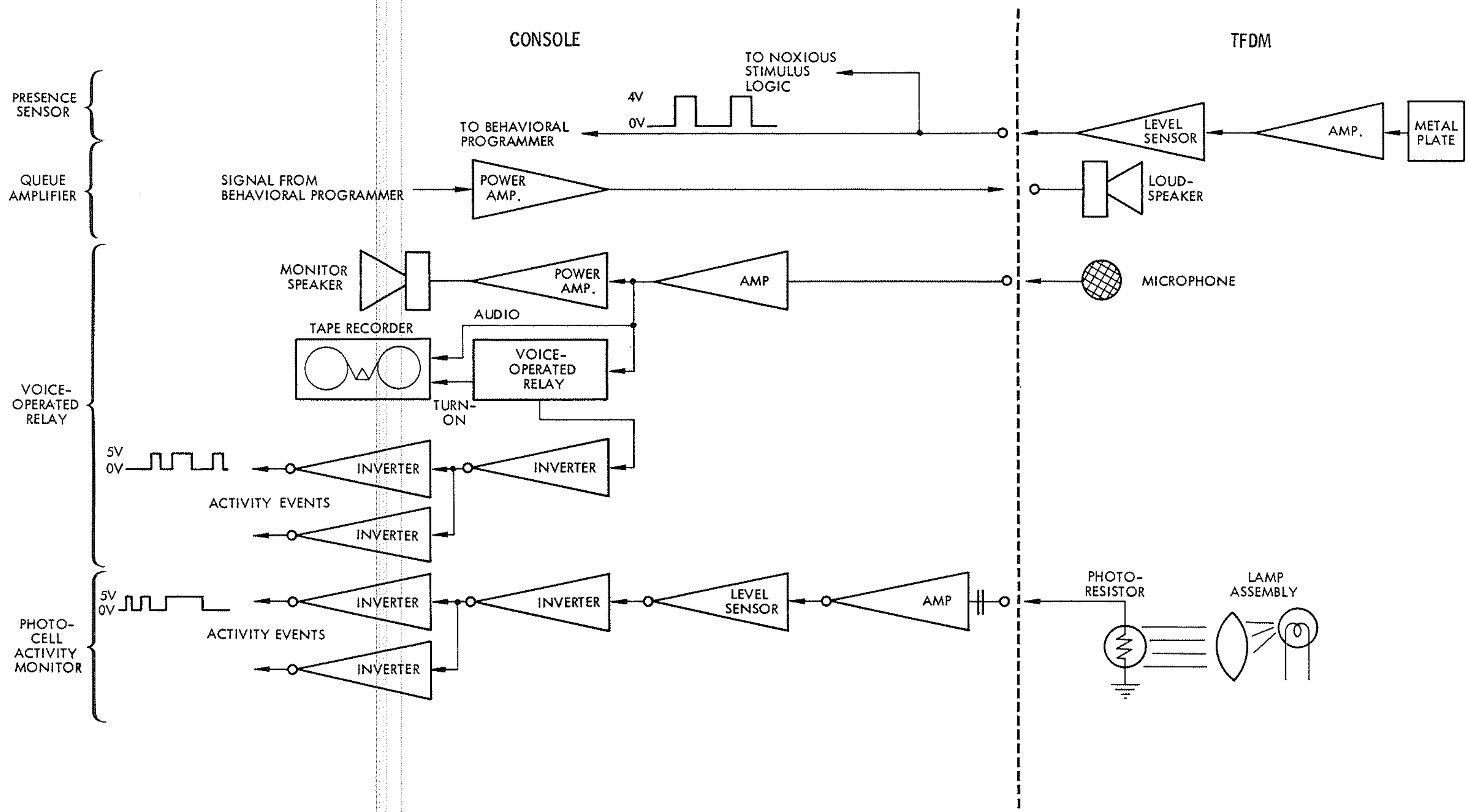


Figure 8 Biomonitoring Subsystem Block Diagram (Photo, Sound and Presence Sensor)

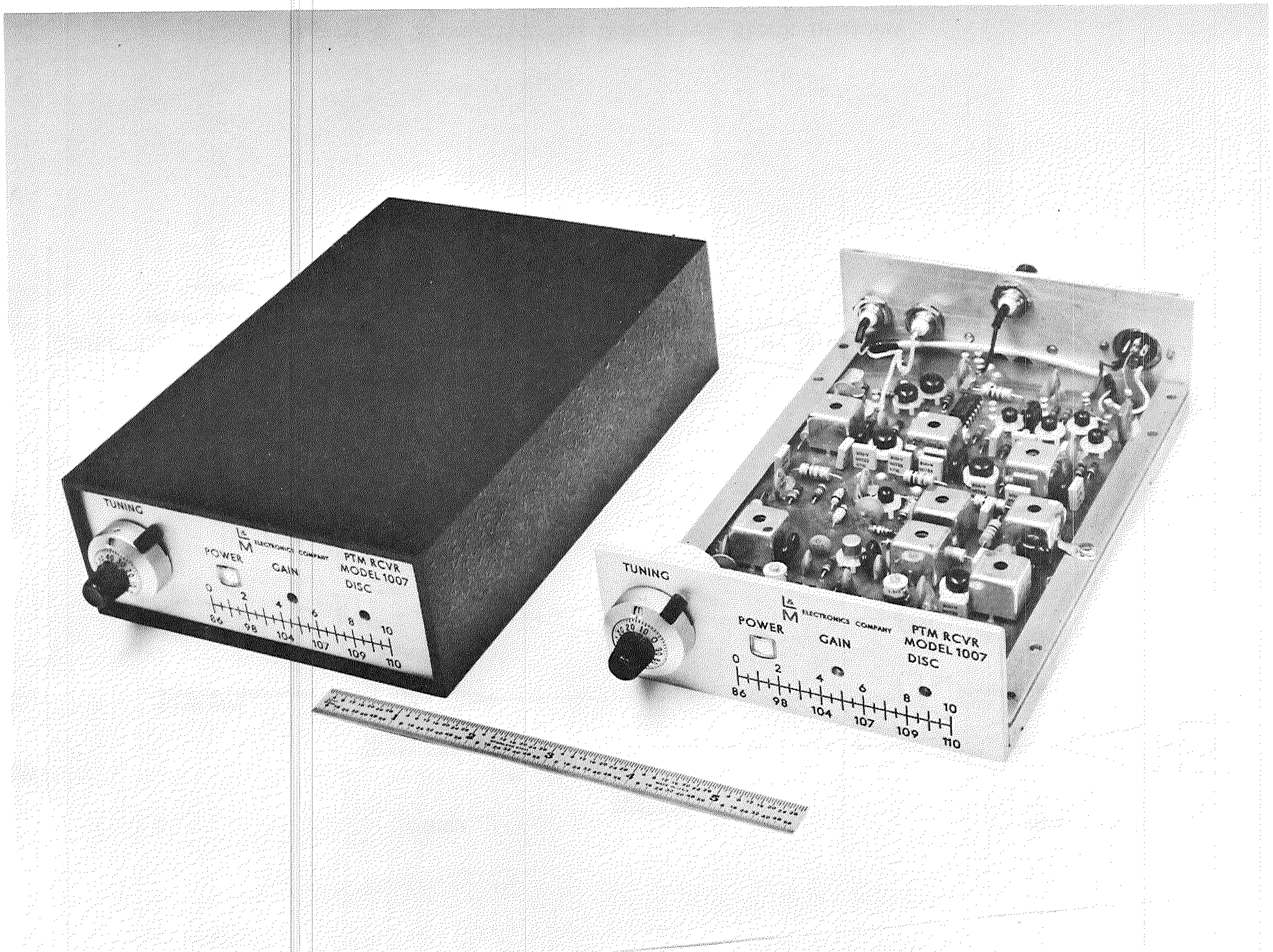


Figure 9 Temperature and ECG Receivers

animal's position or orientation inside the cage or in the retrieval canister.

The transmitters are Whittaker, Type BT2 which operate in the 88-108 MHz band. For proper reception the two frequencies should be at least 1.0 MHz, but no more than 5.0 MHz apart. The receivers are L & M, Type 1007, designed to operate with the Whittaker transmitters.

According to the manufacturer's specification the transmitter produces a field strength of 5 μV/m at a distance of 10 feet. If it is assumed that the radiation pattern is that of a dipole this corresponds to a total radiated power of 10 μW or -80 dBm. Presumably, this is the peak pulse power.

The receiver is specified to have a tangential sensitivity of -99 dBm and a noise figure of 7 dB.

Combining the two specifications implies that a total transmission loss of approximately 19 dB is acceptable.

The main cage is a metal cylinder, 34" in diameter and 48" long with one end closed by a metal grill and the other end largely open. Since the diameter is much smaller than a half wave length of the transmitted signal such a metal cylinder will act as an attenuator rather than as an ordinary wave guide.

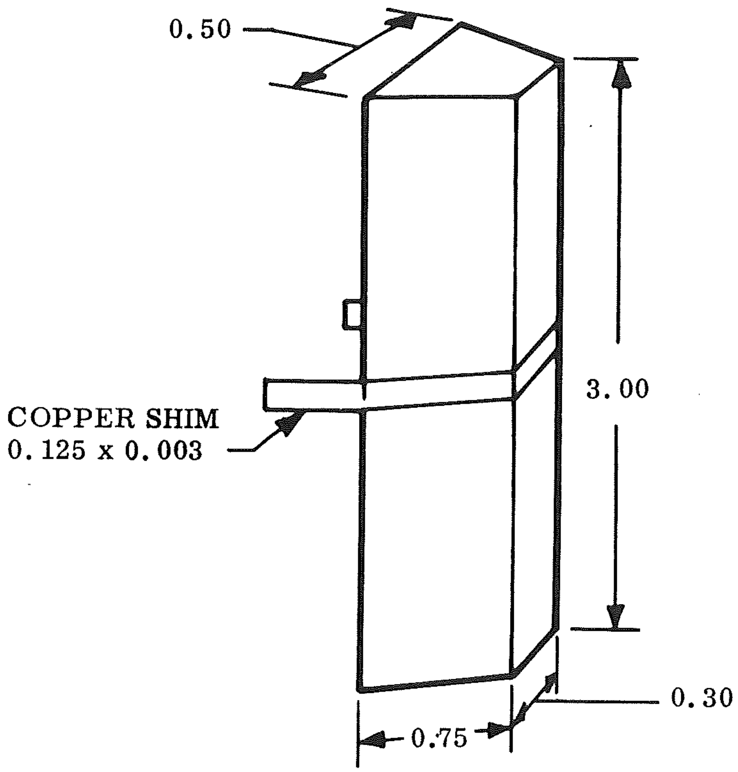
Each of the telemetry transmitters can be considered as a magnetic dipole and will excite one or more of the normal modes in the cross-section of the cage. The field pattern which is characteristic of each excited mode will be repeated in other cross-sections without rotation or phase shift, but attenuated exponentially with the axial distance between cross-sections. The attenuation constant is largely independent of frequency but is inversely proportional to the diameter and is different for each mode. A summary of the fields and characteristics of the four lowest modes (See Ref. 3) is presented in Table 1. It is seen that there will be at least 39 dB attenuation from one end of the cage to the other. If, however, the transmitter magnetic dipole is close to the closed end of the cage the dominant mode will be weakly excited, if at all and the other modes will give at least 24 dB more attenuation.

From this it is apparent that an antenna placed at or near the open end of the cage would not be satisfactory. The only other area available for placing the antenna is a narrow strip along the side where the flexible liner is attached to the cage structure.

Based on the results of the cage antenna development tests, the system was designed as shown in Figures 10 and 11, using four magnetic dipoles located along the cage wall.

MODE	TE_{11}	TE_{21}	TM_{01}	TE_{01}
CUT-OFF FREQUENCY	$\frac{C}{3.412a}$ = 204 MHz	$\frac{C}{2.057a}$ = 339 MHz	$\frac{C}{2.613a}$ = 266 MHz	$\frac{C}{1.64a}$ = 425 MHz
ATTENUATION	0.94 dB/INCH	1.56 dB/INCH	1.23 dB/INCH	1.96 dB/INCH
MAGNETIC FIELDS:				
AXIAL, Hz (PHASE REFERENCE)	ZERO ON AXIS; MAXIMUM AT WALL, BUT WITH TWO NULLS	ZERO ON AXIS; MAXIMUM AT WALL, BUT WITH FOUR NULLS	NONE	MAXIMUM ON AXIS AND AT WALL; ONE NULL IN BETWEEN
CIRCUMFERENTIAL, H_ϕ (QUADRATURE)	ZERO ON AXIS; MAXIMUM AT WALL, BUT WITH TWO NULLS IN POSITIONS 90° FROM NULLS OF Hz	ZERO ON AXIS; MAXIMUM AT WALL, BUT WITH FOUR NULLS	ZERO ON AXIS MAXIMUM AT WALL	NONE
RADIAL, H_r (QUADRATURE)	MAXIMUM ON AXIS; ZERO AT WALL	ZERO ON AXIS; ZERO AT WALL	NONE	ZERO ON AXIS; ZERO AT WALL

Table 1 Modes in Circular Waveguides



FERRITE MATERIAL:

CERAMIC MAGNETICS NO. C-2075

$$\left.\begin{array}{l}\mu_o \geq 25 \\ Q \geq 150\end{array}\right\} \text{AT 100 MHz}$$

Figure 10 Ferrite Core Antenna

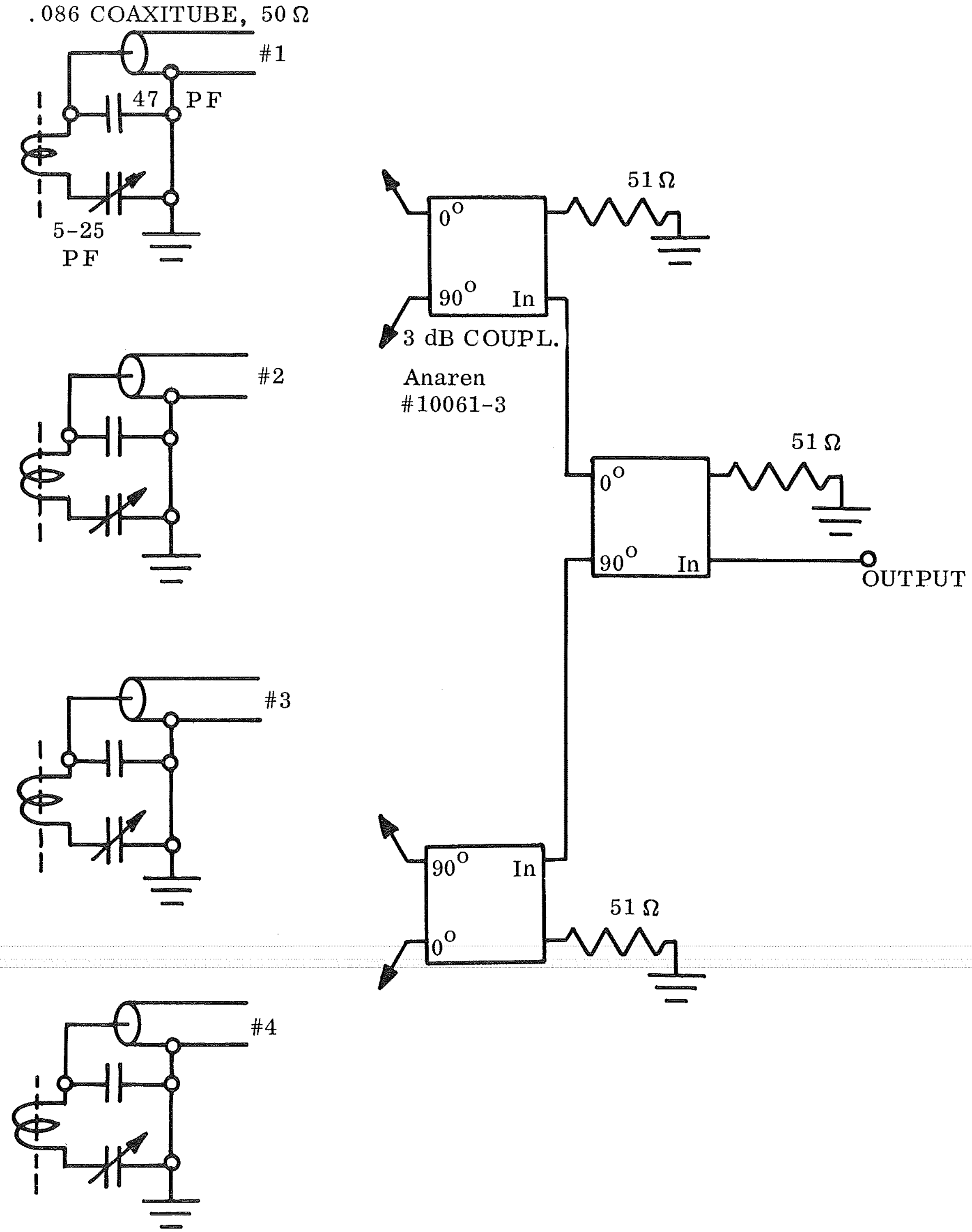


Figure 11 Cage Antenna

Each magnetic dipole consists of a 3" long rod of ferrite with a single turn coil. The four dipoles are connected through 50Ω coaxial cable to a signal combiner consisting of three 3 dB/90° hybrids.

With the connections shown in Figure 11, the signals from two neighboring dipoles cannot cancel due to the 90° phase shift in each hybrid. However, a signal loss of approximately 5 dB results from the use of this combiner.

Since the canister is small and made of dielectric material, a single-turn coil surrounding the canister can be tuned to the transmitter frequency and will always receive a strong signal when the test animal is inside.

In order to transmit the signals from both cage and canister on one cable, they are combined as shown in Figure 12. The signal from the cage antenna is amplified before combining with the canister signal.

Activity Monitoring.- The activity monitoring subsystem consists of three different and independent elements. Activity of the primate is registered whenever the animal (1) changes the implanted biotransmitter field strength/antenna relationship, or (2) changes the implanted magnet flux field/magnetometer relationship, or (3) interrupts a light beam.

The field strength activity subsystem provides an output pulse whenever the transmitter (animal) moves. Both the temperature and electrocardiogram circuits provide such outputs. It is to be noted that the output is associated with a change of field strength, not just attainment of a threshold value.

In addition to the two biotelemetry sensors, a small permanent magnet can be implanted in the animal. Four magnetometer pick up coils (See Fig. 7) are arranged about the cage. These coils will pick up the magnetic field surrounding the animal and with subsequent circuitry provide a pulse whenever the magnet (animal) moves.

The photocell/light source subsystem (See Fig. 8) is a single beam of light shining horizontally across the cage approximately 8 inches above the floor. An infrared filter is used to reduce the visible light level within the cage.

Activity of the animal is registered on the control panel by a momentary white light and a digital count whenever any or all of the three appropriate activity sensors are stimulated. The counters may be cleared manually to zero when desired.

Sound Detection.- The sound detection system consists of a microphone located in the cage roof which receives the animal's vocalizations. These sounds are broadcast to the operator through the control-console mounted loudspeaker (See Fig. 13). Vocalization of the primate causes a tape recorder to start and to record the primate's vocalization. A 3.5 second

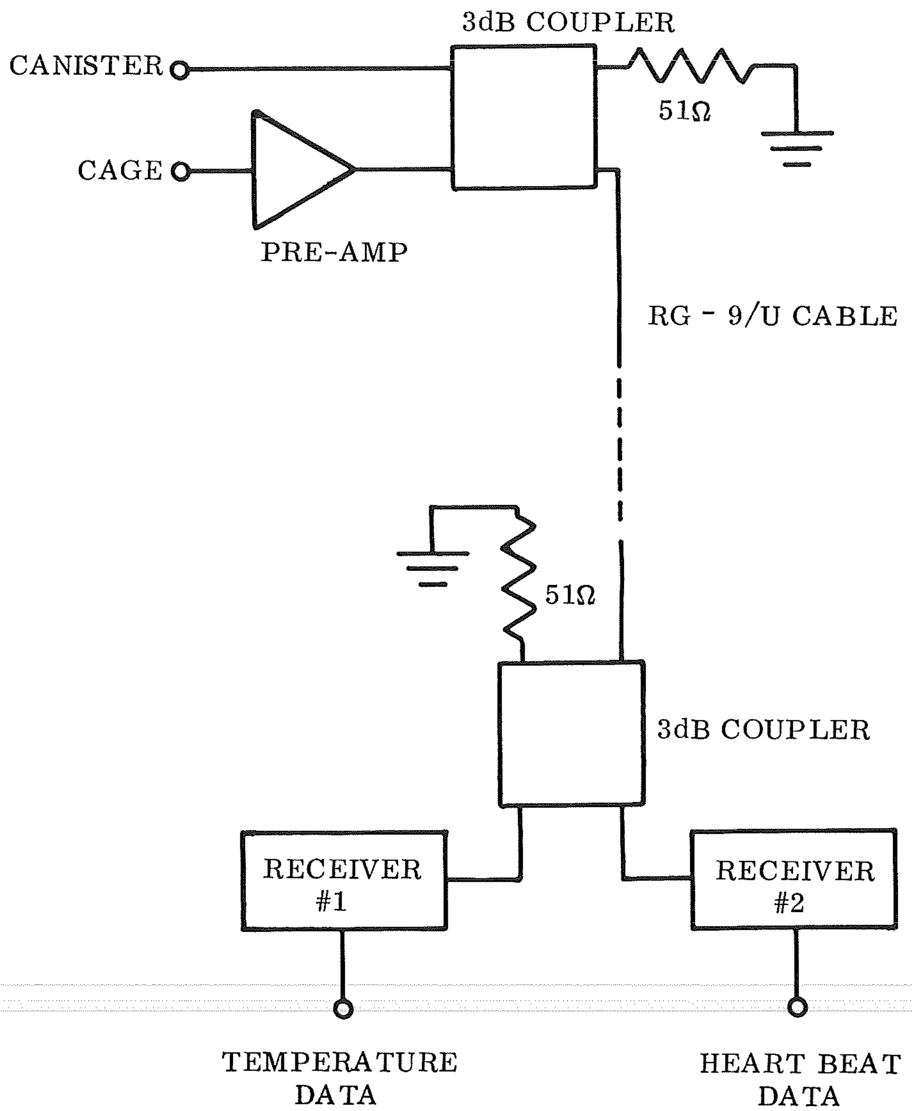


Figure 12 RF Transmission System

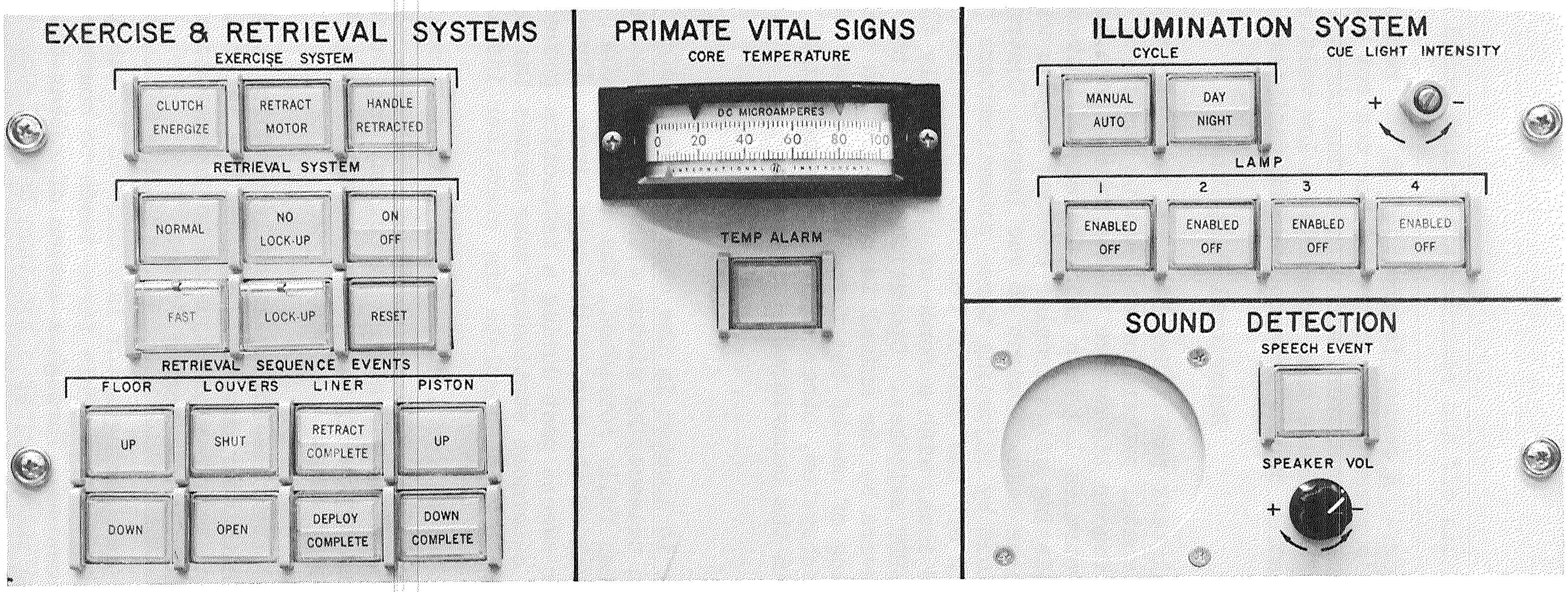


Figure 13 Control Panel (Exercise, Retrieval, Vital Signs, Illumination, and Sound Detection)

time delay relay shuts off the recorder after each sound event.

Presence Sensor.- A sensor is provided in the retrieval canister which detects the animal's presence by virtue of his contact with one or more copper bands inside the canister, and with a ring located at the entrance to the canister. The primate thus completes a low voltage electrical circuit providing an indication of his presence in the canister.

Behavioral Task Panel

The behavioral task panel (See Fig. 14) consists of three small levers arranged in a horizontal pattern below, and to the right (as the animal views it), of the feeder lip device in the cage. Each lever is 0.38 inch in diameter and protrudes 1.0 inch into the cage. Surrounding each lever is a cue lamp consisting of a circular colored acrylic window which is back-lighted by three twin-filament 28 vdc lamps. Control of cue lamp intensity is provided by adjusting three potentiometers (one for each lever) located on the back of the control console. Operation of each lever upwards approximately 0.25 inch, with a force of approximately three ounces, causes actuation of two SPDT switches. Operation of any of the three behavioral panel subsystem levers by the animal is registered on the control panel by a momentary lighting of one of the three white lights. Control of the behavioral panel subsystem, other than varying cue light levels as discussed above, is vested in the behavioral programmer.

Exerciser

The exerciser is located in the cage roof assembly. It is a four-stage cantilever-mounted telescoping piston with a total stroke of 43.9 inches. (See Fig. 15). When fully retracted, the handle resides in a well in the roof above the level of the top of the cage liner. Thus, no conflict can occur as the liner sweeps past during a retraction procedure. A rectangular box on top of the outermost stationary tube houses the various electro-mechanical components which complete the exerciser installation.

The handle is sized for a rhesus such that only one hand will fit on either side of the center post. The handle is pinned to the center post, permitting it to pivot 45° in either direction, thus encouraging a two-handed usage of the device by the animal. Furthermore, the handle can rotate about the telescoping axis.

Each stage of the telescoping assembly contains a pair of spring-loaded teflon slippers which bear outwardly against the inner diameter of the next larger tube. These pads may be adjusted to produce more or less friction as desired, by changing the spring force.

A constant force spring motor is connected to the innermost stage by a small diameter wire rope. This force tends to counter-balance the dead weight of the mechanism. Through a system of rubber-toothed belts, the drum of the spring motor drives a ten-turn helical-wound potentiometer, and

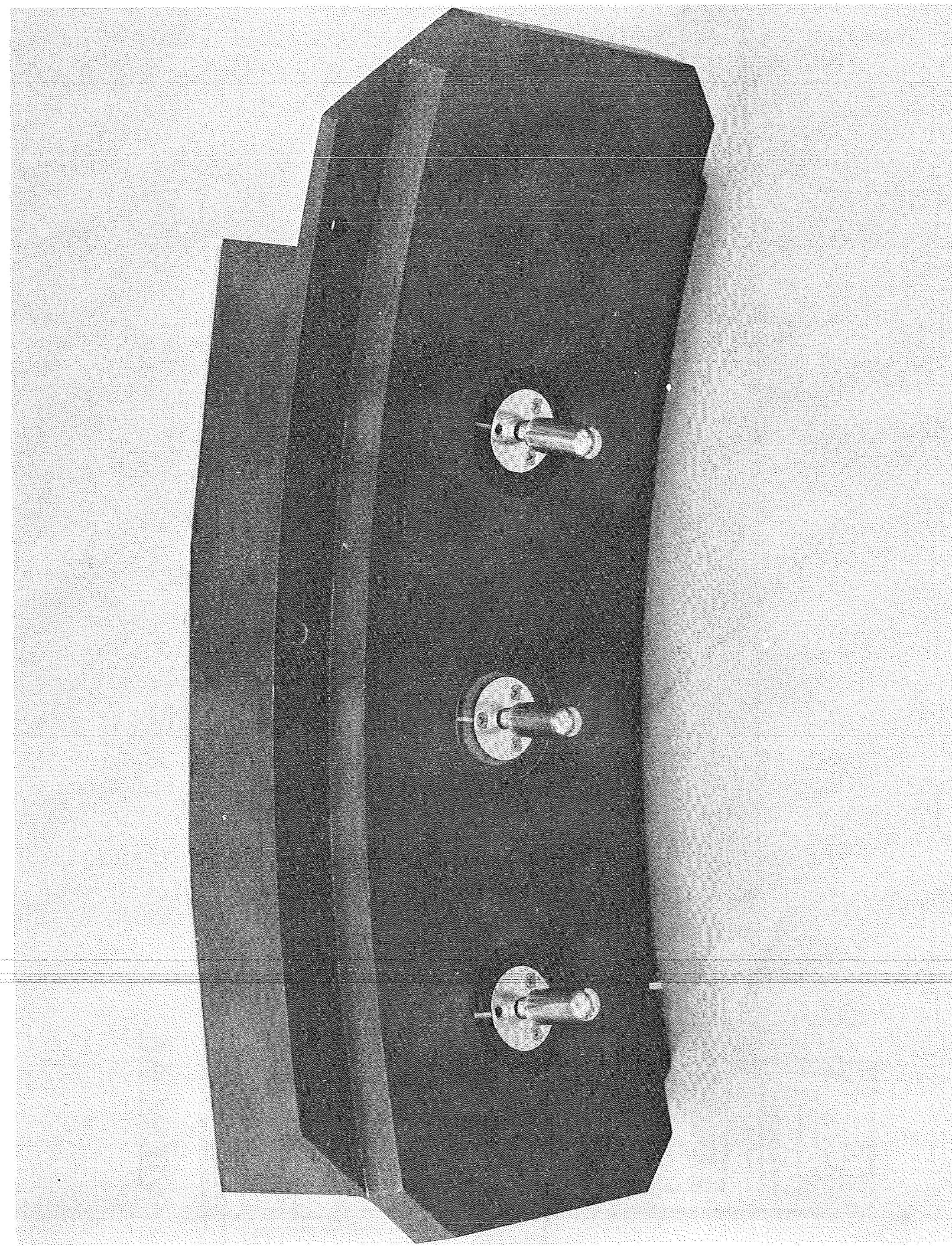


Figure 14 Behavioral Task Panel

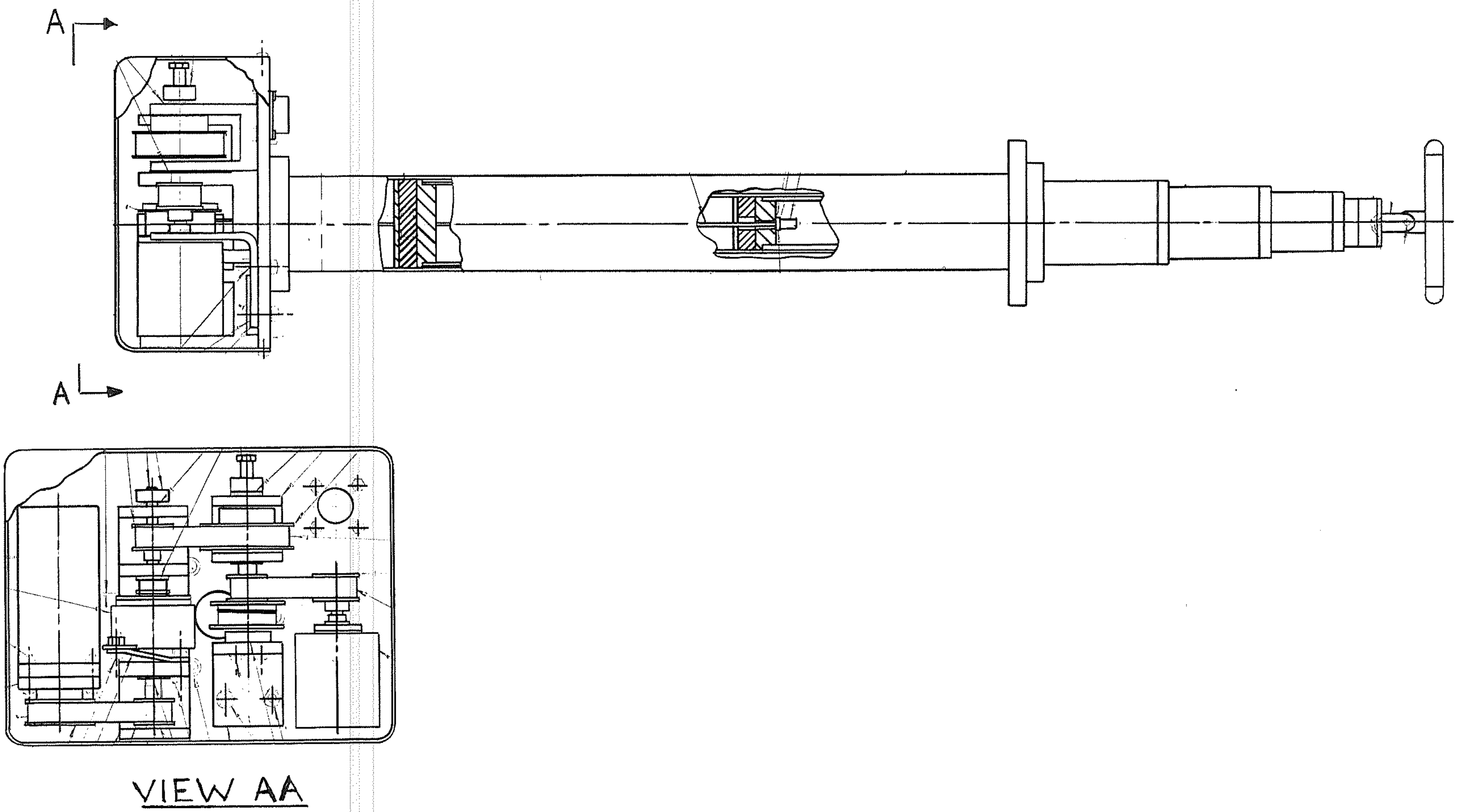


Figure 15 Exercise Unit

in turn may be driven by a gear motor through a solenoid-operated clutch.

The ten-turn potentiometer provides direct analog sensing of exerciser handle position. The gear motor retracts the exerciser by pulling on the small diameter wire rope. The solenoid-operated clutch disengages the gear motor from the drive train, permitting animal operation of the subsystem. The clutch may also be engaged without energizing the gear motor so as to prevent the exerciser from extending downwards from the point where the clutch was engaged. In case of mechanical failure, a manual crank may be inserted through a hole in the rectangular box, engaging a 0.375 inch hex nut. Cranking this nut in a counter clockwise direction (when facing the hole) will elevate the exerciser assembly. The output signal from the 10 turn potentiometer drives a current meter for analog position information, and also provides a voltage signal to comparator circuits for event-type digital information. The event-type information comprises three distinct exerciser handle positions: retracted, up and down.

Mass Measurement Subsystem

The mass measurement subsystem for the TFDM is of the conventional load-cell type and is intended only for operation in one g. Three 75 lb capacity load cells support the entire cage floor including all moving and non-moving parts.

The entire floor including the retrieval piston and actuator is load sensitive and it is constrained radially and rotationally. Four sections of tubing and four electrical cables cross the sensitive interface. They have been arranged carefully to induce as little spring force and hysteresis as possible on the subsystem.

The control unit (See Figure 16) provides a digital visual output and and analog output for recording.

As wastes build up on the floor, changing the tare weight, the option exists of zeroing out this additional tare weight, providing the animal is off the floor. The mass measurement subsystem will also register activity and retrieval events. The load-cells have a safe overload limit of 300% which will easily handle the load associated with the seating of the retrieval piston.

Television Subsystem

The television subsystem consists of the following units:

- Pan and tilt mechanism
- Camera
- Camera control unit
- Zoom lens
- Monitor
- Side mount
- Wide angle lens

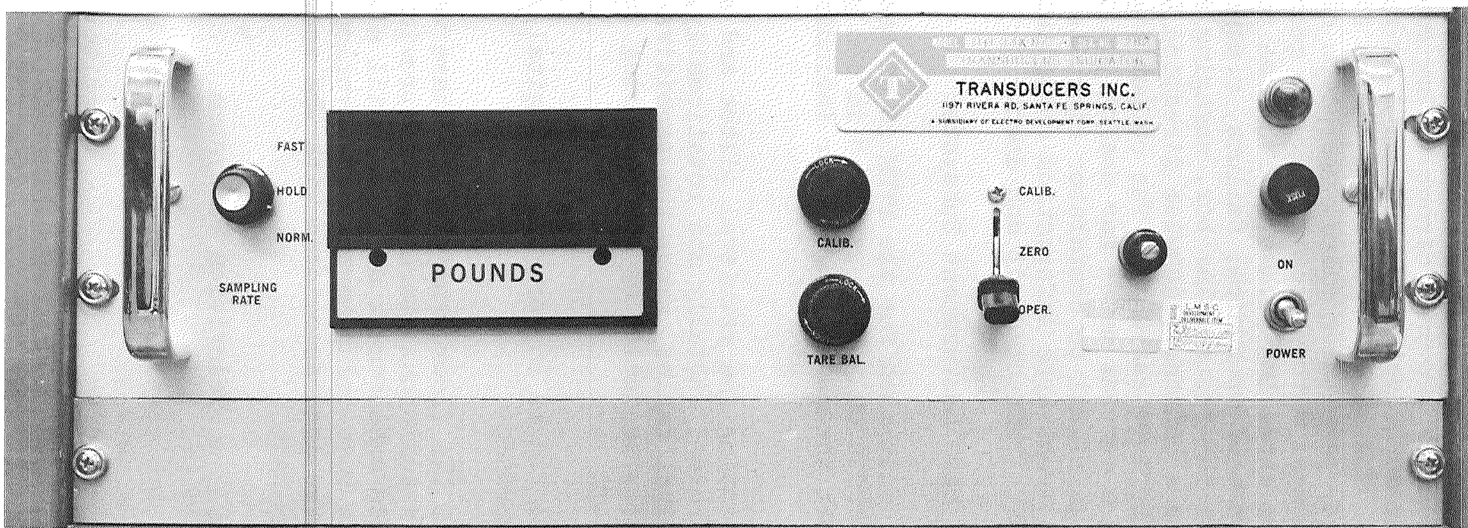


Figure 16 Control Unit for Mass Measurement

Both the pan and tilt and the side mount are designed to accept the same camera, thus a single camera may be switched from one position to the other. In case a second camera, control unit, and monitor are acquired later, two simultaneous cage views may be obtained.

The pan and tilt unit contains the camera and zoom lens (See Fig. 17). It is mounted on the roof of the cage on an inclined plane (10° off horizontal).

Since the zoom lens assembly is a commercial unit normally not used to focus closer than 4 feet, an additional mechanism is installed to provide extra adjustment of the vidicon with respect to the lens. This is accomplished by mounting the camera in two saddles which are driven by a lead screw. The total travel of the camera is 1.0 inch. The camera is totally enclosed within a box which is both light and dust tight. The zoom lens is held stationary within, and comprises an end closure of, the same box. The entire box tilts about an axis near the lens objective thus minimizing the size of the roof penetration. The limits of tilt are $\pm 35^{\circ}$. The tilt axis is rotated to produce 350° of pan. An optically flat window is installed in the base of the unit to provide air-tight integrity to the cage. A long sheet of mylar film is led in front of the window from a supply spool to a motor-driven take-up spool. Periodically, when the exposed mylar becomes dirty from various causes, the take-up is driven to provide a fresh clean sheet of protective film over the glass window. A protective screen assembly between the mylar film and the monkey completes the installation.

All gear motors are the same. All drives have slip clutches, limit switches, and mechanical stops except the mylar film transport which merely has a slip clutch. The zoom lens has remote iris and focus control.

The camera and pan and tilt cables are arranged in a generous spiral to reduce the flexural load on the pan and tilt drive motors. The pan and tilt drives until it encounters an obstacle. The two most prominent interferences are the ducting and the retrieval canister. When it encounters these, the clutches commence slipping and the unit comes harmlessly to rest. The operator is aware of this condition occurring when his picture does not change while the drive switch is actuated.

The side mount is a fixed camera installation with a wide angle lens (95° field of view). The iris of the lens is adjusted manually. The focus is fixed. A window, mylar film transport, and screen are installed for the same reasons as for the pan and tilt unit. One different feature of this installation is the quick removal mechanism. In an emergency, a tee handle on top of the assembly is pulled towards the operator (away from cage). As it rotates downwards, pins disengage, and the whole unit (camera and screen included) drops away from the cage leaving a clear rectangular hole through which the primate may be removed, or a fire extinguisher inserted.

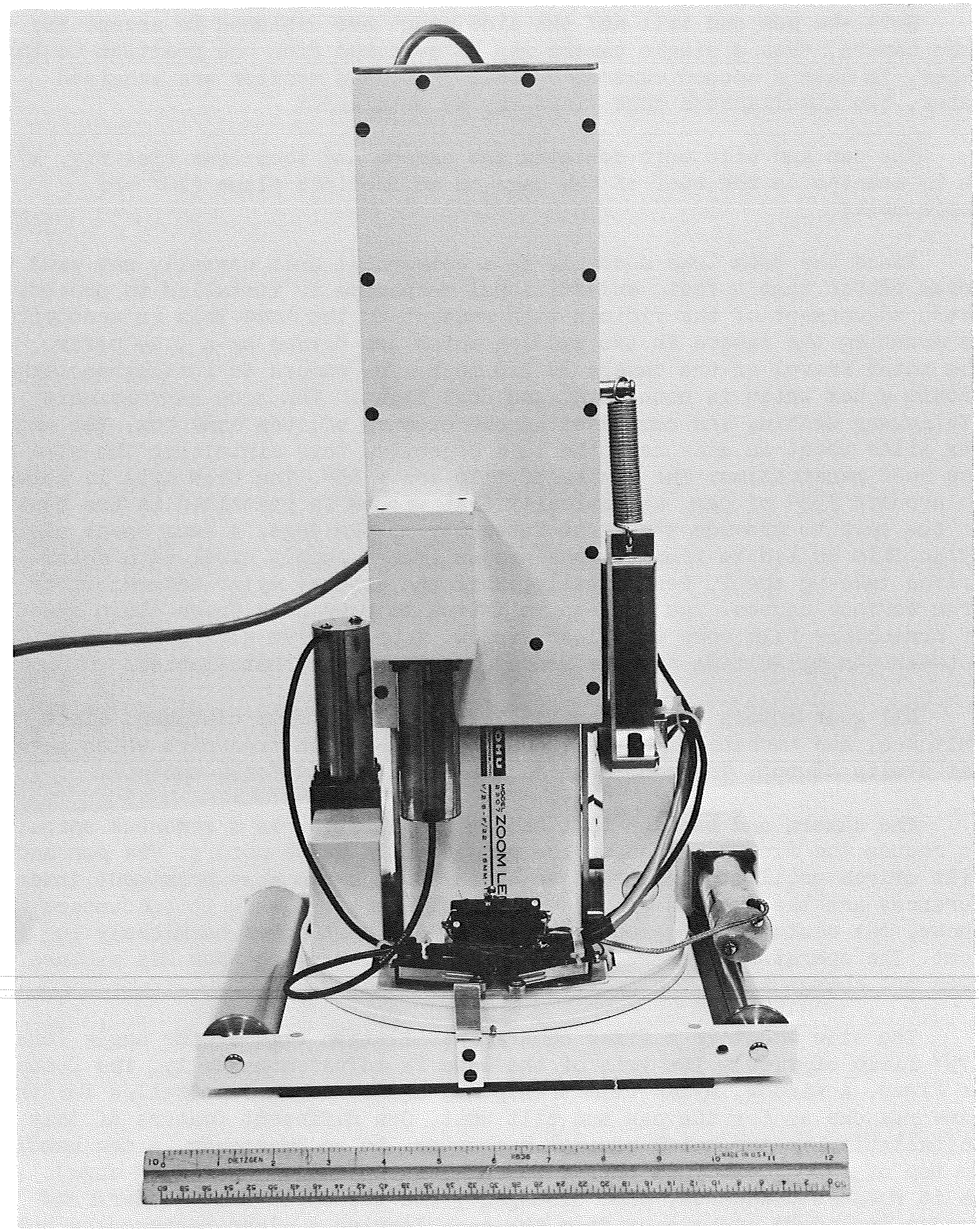


Figure 17 TV Pan and Tilt Unit

Illumination Subsystem

The basic cage illumination comes from four roof-mounted 18 inch long Vita-Lite SCD 15W fluorescent lamps made by Duro Test Corporation. Supplementary illumination is provided by two small incandescent night lights in the roof assembly, by all cue lights, and by whatever light may come through the social panel. The fluorescent lamps are powered by 400 Hz 115 V ac current using a GE FS-2 starter and a GE 9T39Y2972 ballast. Fluorescent lamps are sequentially extinguished to adjust the light intensity.

The night lights and all cue lights except for the exerciser are modulated by adjusting potentiometers on the rear of the control console. The exerciser cue lights are adjusted on the control panel.

Basic control of the day/night cycle is vested in the behavioral programmer. A manual override permits operator control when desired.

RELIABILITY AND QUALITY ASSURANCE PROGRAM

Quality and reliability surveillance and control functions were implemented in accordance with the requirements in the statement of work.

Design drawings, specifications and test procedures were reviewed and approved by the Product Assurance Program Representative (PAPR) who was assigned to the program. Recommendations by the PAPR to define inspection criteria, and to improve reliability were incorporated into the engineering documentation.

Inspection audit points required during the manufacturing, assembly and testing sequence were annotated on the Work Authorizing Documents (WAD). Nonconformances between hardware and engineering documentation were noted on the reverse side of the WAD and submitted to material review for disposition. Material review, composed of the PAPR and the TFDM Project Engineer, prepared instructions to correct or to use the discrepant hardware.

Integrity of hardware configuration was preserved by several control methods. All incoming raw material and purchases components were inspected to insure compliance with engineering requirements, and the acceptable hardware placed in a locked storeroom. Issuance from the storeroom was verified by inspection. "Red-lined" drawings, signed by the TFDM Project Engineer were used to record changes to original engineering requirements. All changes were subsequently incorporated as engineering change orders thereby insuring compatibility between engineering requirements and the "as-built" hardware.

A project log book was delivered with the TFDM. The log book was started with the initial fabrication of hardware and documentation was added throughout the manufacturing and testing sequences. It is literally a diary of events significant to the TFDM hardware manufacturing and test.

Other documentation, not considered significant, but necessary for administrative or control purposes, and particularly as a "backup" to the log book is retained by LMSC for audit or review.

Significant testing, particularly the fourteen-day acceptance test, was witnessed by the PAPR, who periodically verified data entered in the testing portion of the log book.

In addition, the PAPR verified post-test corrective actions and preparation of the hardware for shipment.

LMSC TEST PROGRAM

The LMSC testing of the hardware for the TFDM can be divided into three basic categories: development, system and acceptance tests. Development testing provided a means for design concept verification with hardware prior to the final detail design and hardware fabrication. System tests were used to measure the performance of a complete sub-system or total system. Acceptance tests were of two types: (1) component acceptance tests and (2) the TFDM acceptance test. A functional test on equipment from suppliers was conducted at the subsystem and system test level. Equipment supplied GFE, such as the behavioral programmer was not subjected to individual acceptance test but was inspected for general condition and for damages resulting from shipment. Programmer performance was determined during the subsequent system testing.

Development Testing

Development testing was conducted to produce engineering information to aid in the design of detail components of subsystems and determine problem areas requiring corrective design action.

Retrieval canister floor load.- The floor of the retrieval canister is located on the floor of the animal cage and serves as a part of the cage floor until the retrieval operation is initiated. At completion of cage roll-up, a pneumatic telescoping elevator, located under the center of the domed canister floor, is actuated. This raises the canister floor upward and forces the animal and floor into the retrieval canister. The floor, thus being inserted into the retrieval canister, is forced into an annular seal located in the lower skirt of the canister cylindrical body. In this position, the floor forms a leak-proof seal allowing removal of the canister, with the primate inside, from the life cell via EVA by the astronaut.

The purpose of this development test was to measure the force required to deform the dome-shaped retrieval canister floor, allowing it to snap in place against the seating ring in the retrieval canister.

The test set up is depicted in Figure 18 and consisted of the following elements:

- o Test stand
- o Hydraulic actuator
- o Hydraulic pump
- o Force gage
- o Retrieval canister seating ring
- o Retrieval canister floor

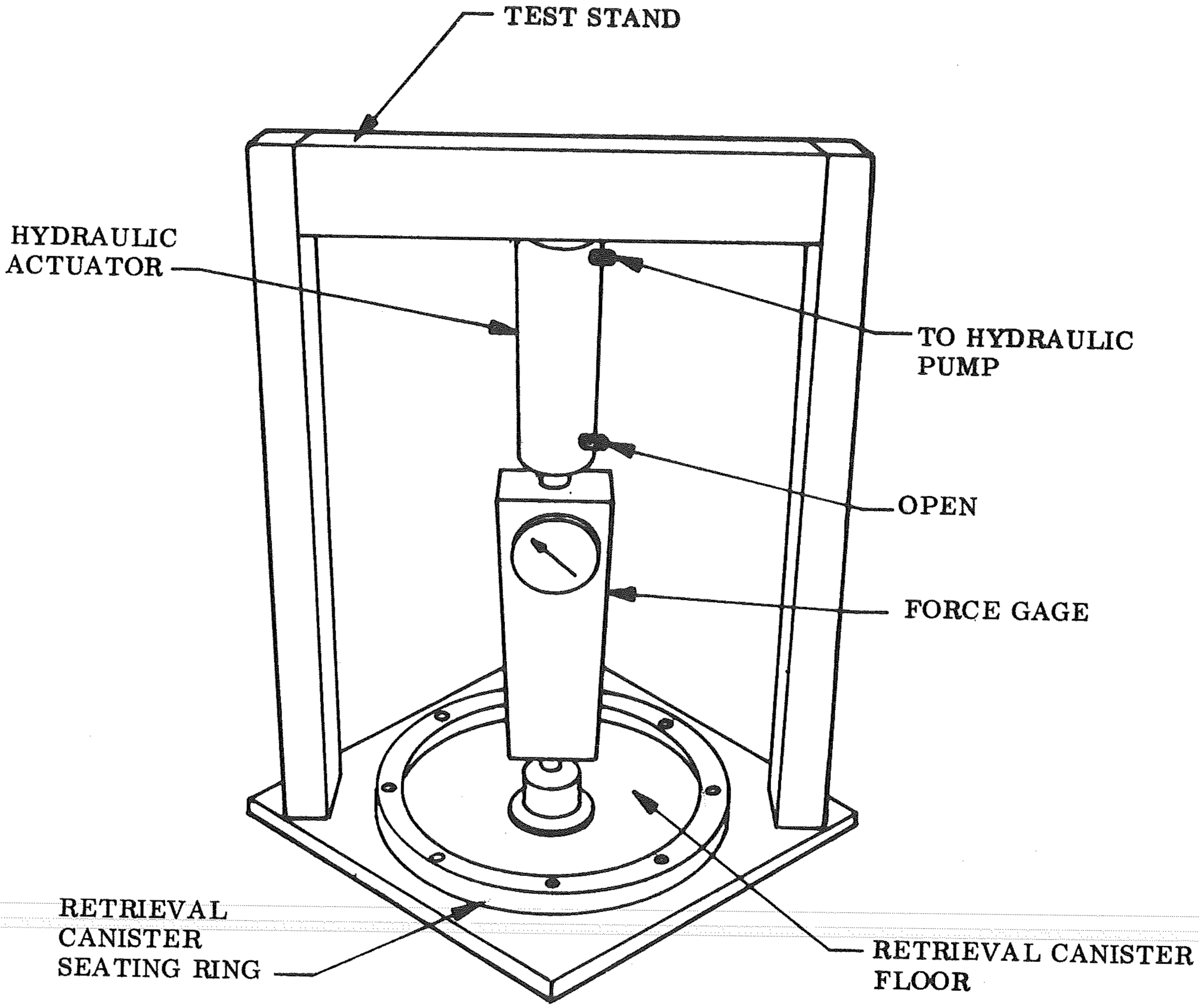


Figure 18 Retrieval Canister Floor Load Test

Pressure was applied to the retrieval canister floor through the actuator system to a maximum of 200 pounds. The retrieval canister floor did not deflect a sufficient amount to allow entry into the retrieval canister seating ring and the test was terminated at this point.

The failure of the retrieval canister floor to deform and allow entry into the seating ring at a force of 200 pounds was proof that this design was not satisfactory. In the final design, the 200 pound load must be taken out through the cage floor assembly. To exceed the 200 pound force places additional structural requirements on the floor which add weight and complexity. The test specimen floor was made of 0.050" 304 corrosion resistant steel. Based on load information from the test, calculations showed that the floor, in order to deflect at a load of 200 pounds, would have to be made of material too thin to be practical. As a result of this test, the design of the retrieval canister floor was changed to one which would lock into the retrieval canister by means of a latching arrangement, thus reducing the force required for seating but still providing a positive seal.

Cage liner retraction test.- A development test using a mockup of the proposed liner retraction system was established to evaluate the retrieval concept for the TFDM. The concept consisted of a liner inside the circular cage which would retract through an exit in the cage wall until it achieved the diameter of the retrieval piston. The liner was to be a 0.016 inch thick stainless steel sheet.

A liner of this description was used in constructing the testing mockup. In addition, the mockup included simulated lip devices, switches, and other cage protuberances.

Testing objectives were primarily concerned with (1) the clearance of cage protuberances and the nature of the liner behavior during the retraction and deployment stages of the liner operation, and (2) observation of the effectiveness of the guide rollers in preventing buckling of the liner as it was subjected to compression after returning to its original position. Also important to the final design was the torque required through the entire sequences of retraction and deployment of the liner. The test configuration can be seen in Figure 19.

Preliminary operation of the liner retraction and deployment showed that the weight of the liner caused it to sag and, as a result, drag on the floor of the cage during the retraction and deployment operations. Because of the dragging, the edge of the window cutout was catching on the simulated switches during the deployment cycle. Two modifications were added to the mockup to prevent this. A roller was positioned at the exit of the cage so that it supported the weight of the liner at this point. The roller also allowed the liner to roll up evenly on the take-up spool. It was observed before this modification that the liner weight caused the liner to roll up in an uneven manner.

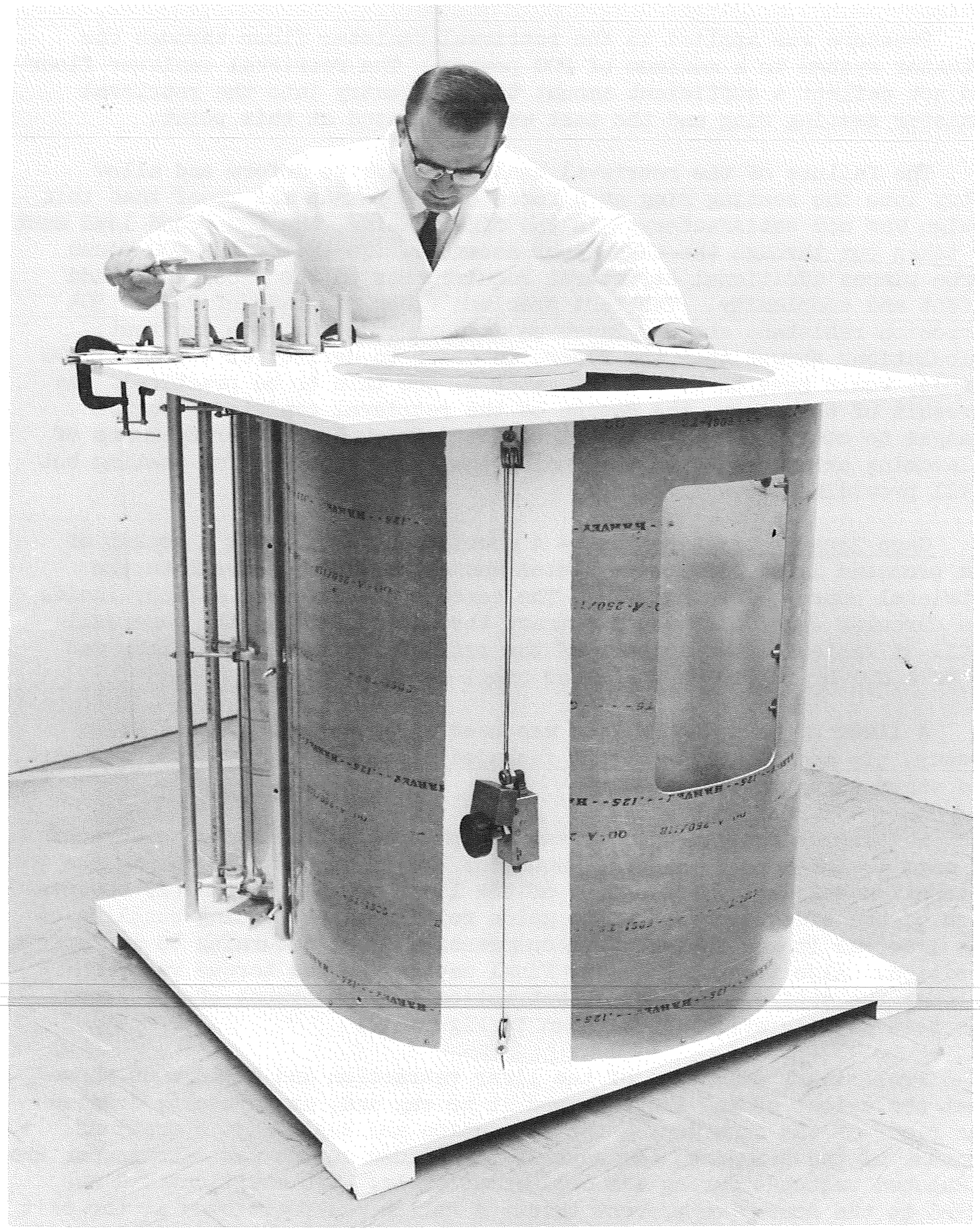


Figure 19 Cage Liner Retraction Test (Basic)

The second modification involved the installation of a tether system on the mock up. The tether was designed to exert a constant force on the top and bottom of the liner. The system is shown in Figure 20 and illustrates the manner in which the weight shown in the photograph was used to exert the constant force.

The tether prevented the liner from sagging because it kept the bottom of the liner in the same semi-elliptical shape as the top. This effect aided in cantilevering the entire liner from where it was attached to the cage wall. As a result, the design modification solved the problem of the social window opening catching on the switches during deployment.

The interaction of the liner with its take up spool and guide rollers was observed during liner retraction and deployment. The liner experienced a clock-spring type action in the rolled-up mode and tended to unwind like a clock spring when deployment was initiated. As a result, two additional modifications were made to help contain the liner. The liner was creased so that it was tangent to the spool's curvature near the point where it was attached, and the guide rollers were placed to surround the take-up spool (Figure 19). In this way, all the energy stored in the wound-up liner was channeled into the deployment of the liner.

After the above modifications were made to the mockup, no observable faults were found in the liner interaction with the takeup spool or guide rollers. No permanent set in the liner was noted because it was wrapped on a 5 inch diameter spool (See Figure 19), nor was there any binding or surface irregularities experienced by the liner as it wrapped upon or unwrapped from the takeup spool. No problems were noted during the retraction phase, however, during the deployment, a slight interference was observed as one of the rollers fell into an opening in the liner. Three rows of rollers were found adequate in containing the liner during the retraction/deployment stages and when preloading was applied to the liner at full deployment.

Very good repeatability was observed when the liner was deployed. (See Figure 21). The liner repeatedly "seated" in the same manner time after time when it was subjected to preloading. Due to preloading, a considerable force was required to deform the liner inward toward the cage center, even when the force was exerted on the window bars. In addition, no gap appeared where the cut-outs around the switches or lip devices were located.

The holes in the liner were elongated to allow sufficient clearance for switches and lip devices during retraction and deployment. The elongated portion of the hole was determined from a layout of the liner assuming it would become successively smaller in diameter as it was retracted. This method proved valid, for later measurements made on the mock up indicated that adequate clearance existed between the cage protuberances and their clearance holes.

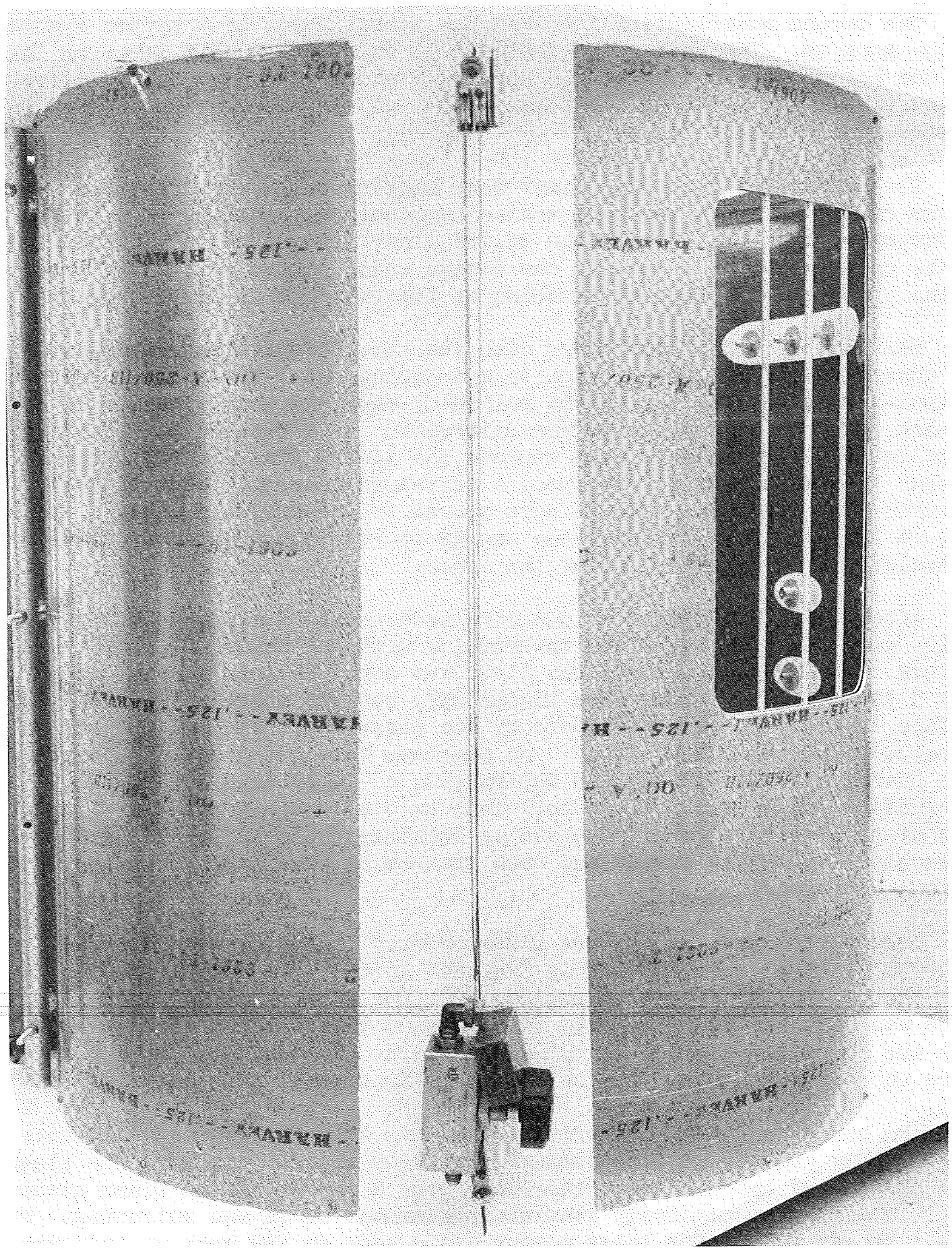


Figure 20 Cage Liner Retraction Test Tether (Modification)

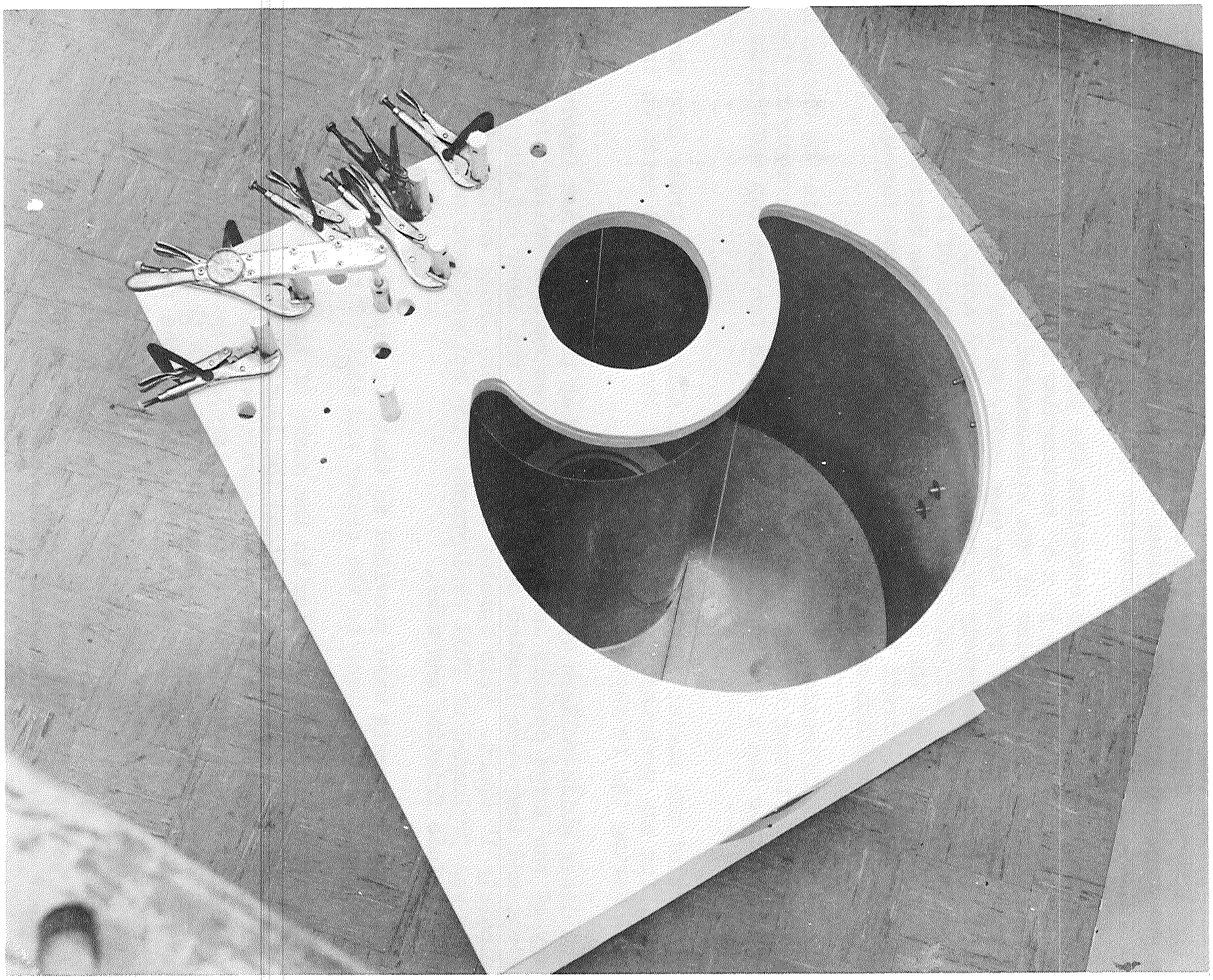


Figure 21   Liner Retraction Spool and Guide Rollers

Torque requirements to retract and deploy the liner were found to be within calculated limits. A maximum of 200 inch lbs. was required to retract the liner. Deployment saw the maximum torque reach 75 in lb. Less torque was required to deploy the liner due to the energy stored in the tightly rolled up liner during retraction cycle.

The mockup was also used to establish the parameters for the installation of the side TV camera. A 5" x 6" rectangular hole was cut in the liner to accommodate the field-of-view of the side-mounted TV camera. The cutout was located approximately 7" from the cage exit, so that when the liner was retracted, this hole immediately exited from the cage area. Measurements performed on the mockup indicated that a maximum distance of 1-1/2" existed between the cage wall and the cutout in the liner as it was retracted. This was not big enough to permit a primate to leave the cage area through the hole during the retraction or deployment cycles.

All of the modifications made on the mockup were adopted in the design of the TFDM. The tether system used a constant torque motor in applying the force to the liner and a separate motor was provided for the top and bottom tethers.

No part of the social window or bars were allowed to protrude into the cage area; for any protrusion on the inside of the liner would catch on the cage exit during the retraction cycle.

The liner guide-rollers were located so that they would not interact with any of the large cutouts in the liner. Three rows of rollers were sufficient and they were located on both sides of the liner and spaced approximately 1" apart. This spacing eliminated any local buckling when the liner was preloaded at full deployment. The rollers were made of Teflon to reduce friction and wear.

Various adjustments were provided so that the liner's takeup spool could be aligned with respect to the center and exit of the cage.

Food tablet vibration.- Prior to the start of the feeder design, the ability of the food tablets to withstand the launch vibration load was determined. An analysis of the dynamic environment of the Saturn S-1B booster system was conducted and vibration levels selected for the tablet test. While an ultimate test was planned to vibrate the tablets in the feeder itself, a preliminary step was to determine the tablet's basic susceptibility to damage from vibration. For this preliminary test, vibration levels were chosen which were estimated to be above the levels which would be seen in a feeder of optimum design during an actual launch. Survival of tablets in this preliminary test, therefore, would almost assure their survival in the actual feeder.

The specimens submitted for test were two types of monkey food tablets as follows:

Specimen 1: Coated tablets - Purina Monkey Chow tablets #5, plus 80 Sucrose - $CaCO_3$ coating, 569.2 gms total weight of tablets.

Specimen 2: Uncoated tablets - Purina Monkey Chow tablets #1B, surface fortified polished, 574.2 gms.

Before testing, the condition of typical tablets was recorded as shown in Figures 22 and 23. Each specimen of tablet was then loaded into a separate one-pint metal container and packing was used to fill the void space in the top of the can. As shown in Figure 24, the packing in both cans consisted of one layer of 1/16" Teflon sheet placed next to the tablet, several layers of 1/4" Foamcore material consisting of two layers of cardboard with a rigid polystyrene inner layer, and a 3/8" polyurethane foam insert. Preload and allowable excursion was approximately 10 lb/ft^2 and 1/8" respectively, and was obtained by inserting the proper number of Foamcore spacers, thus adjusting the compression of the polyurethane foam which provided the preload.

The two specimens were attached to the shake table assembly by a simple fixture, as shown in Figure 25. The specimens were then subjected to both a sine and a random vibration test for a duration of 5 minutes each in the longitudinal axis as follows:

Sinusoidal

Freq. Range (Hz)	Amplitude
20-60	.03 to .048 inches
30-130	9g
130-190	.010 to .012 inches
190-2000	22g

Random

Freq. Bandwidth (Hz)	Spectral Density (g^2/Hz)	Overall g
20 - 200	3 db/oct. rise to 0.45	
200 - 500	0.45	24.2
500 - 1000	3 db/oct. roll off to 0.25	
1000 - 2000	0.25	

Figures 26 and 27 show graphically the desired test levels, while Figures 28 and 29 show traces of the actual inputs as obtained from test instrumentation.

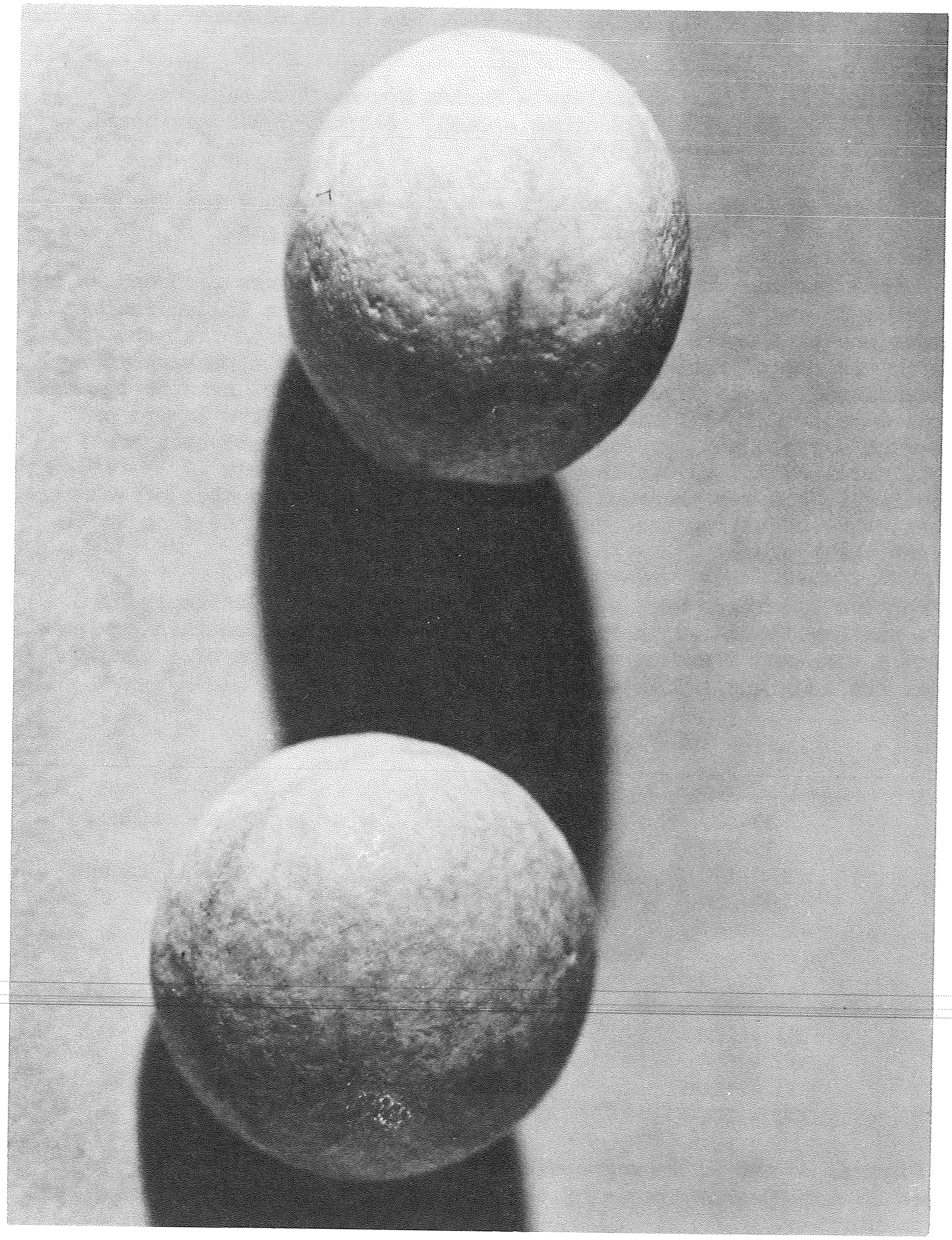


Figure 22 Coated Tablets

Figure 23 Uncoated Tablets

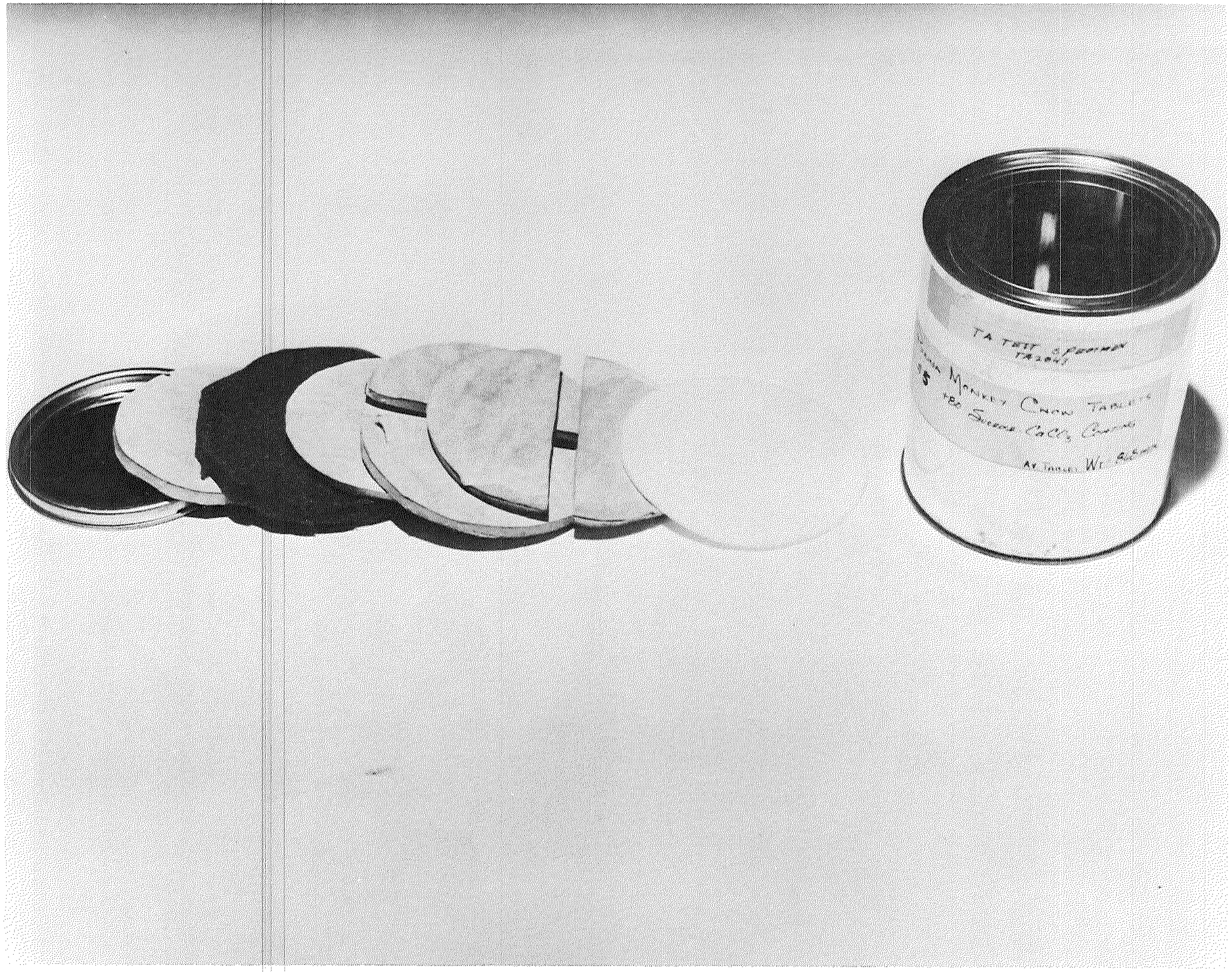


Figure 24 Tablet Vibration Packaging

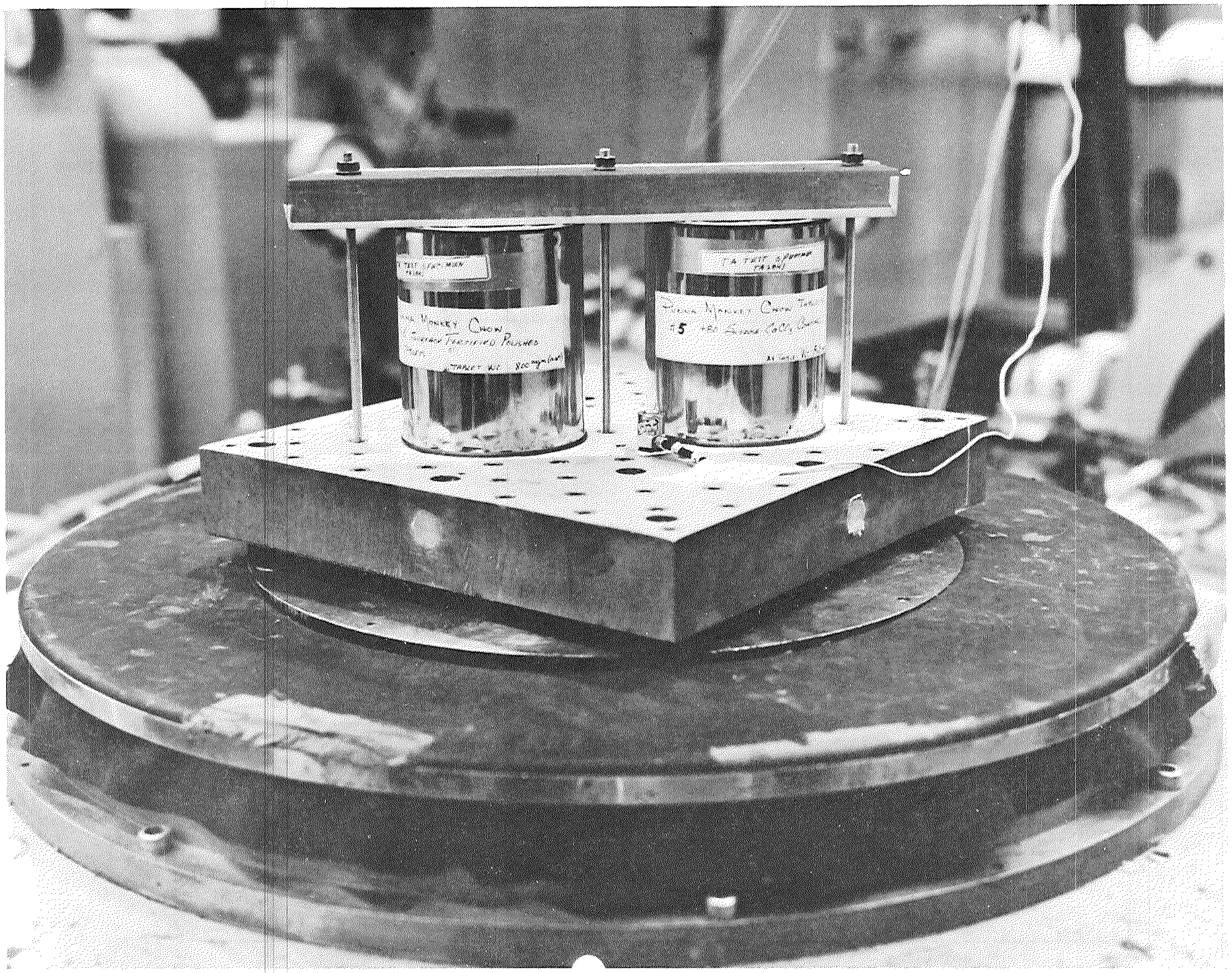


Figure 25 Specimen Shake Table Installation

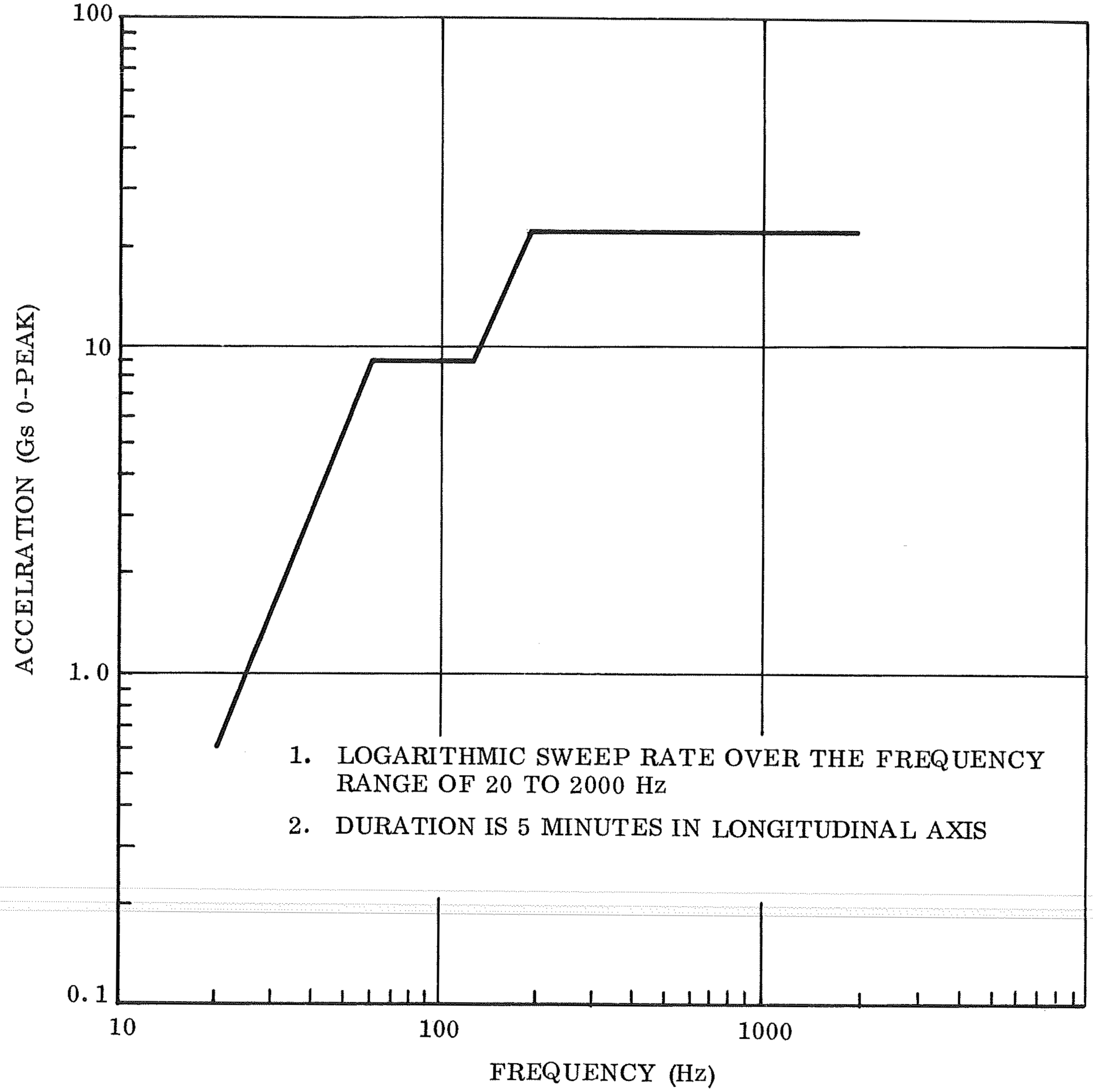


Figure 26 Sinusoidal Vibration Test Spectrum

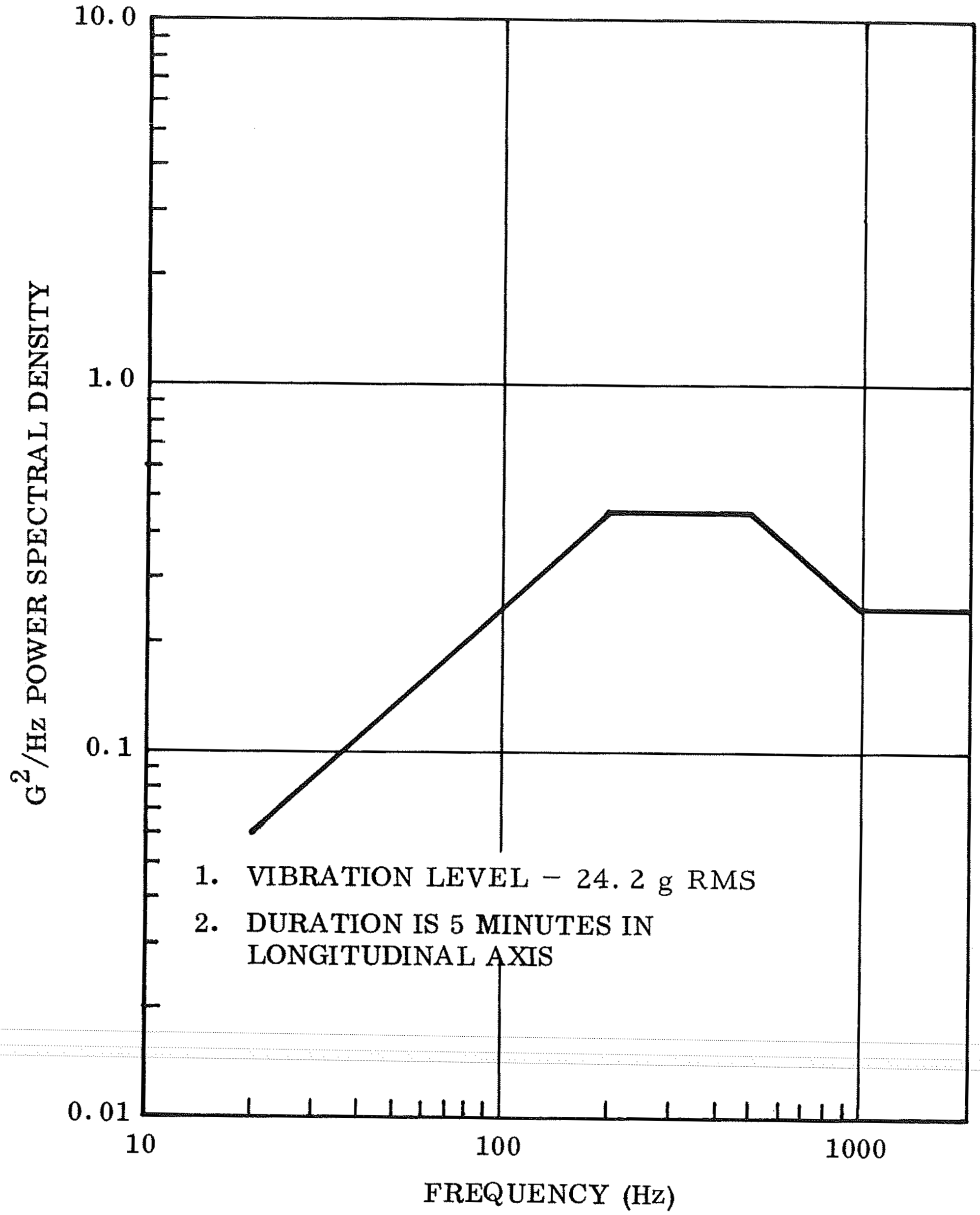


Figure 27 Random Vibration Test Spectrum

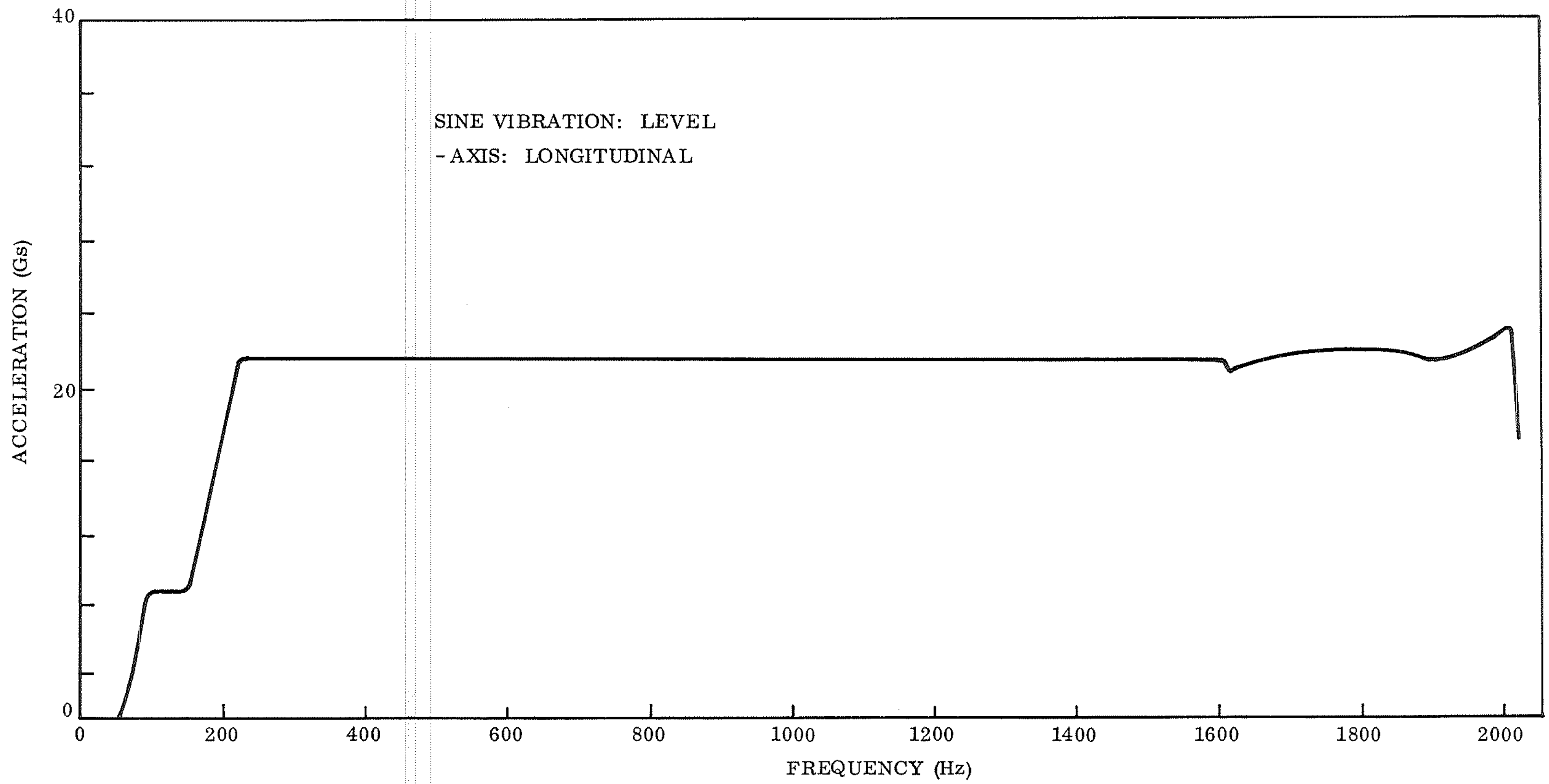


Figure 28 Vibration Test Trace (Sinusoidal)

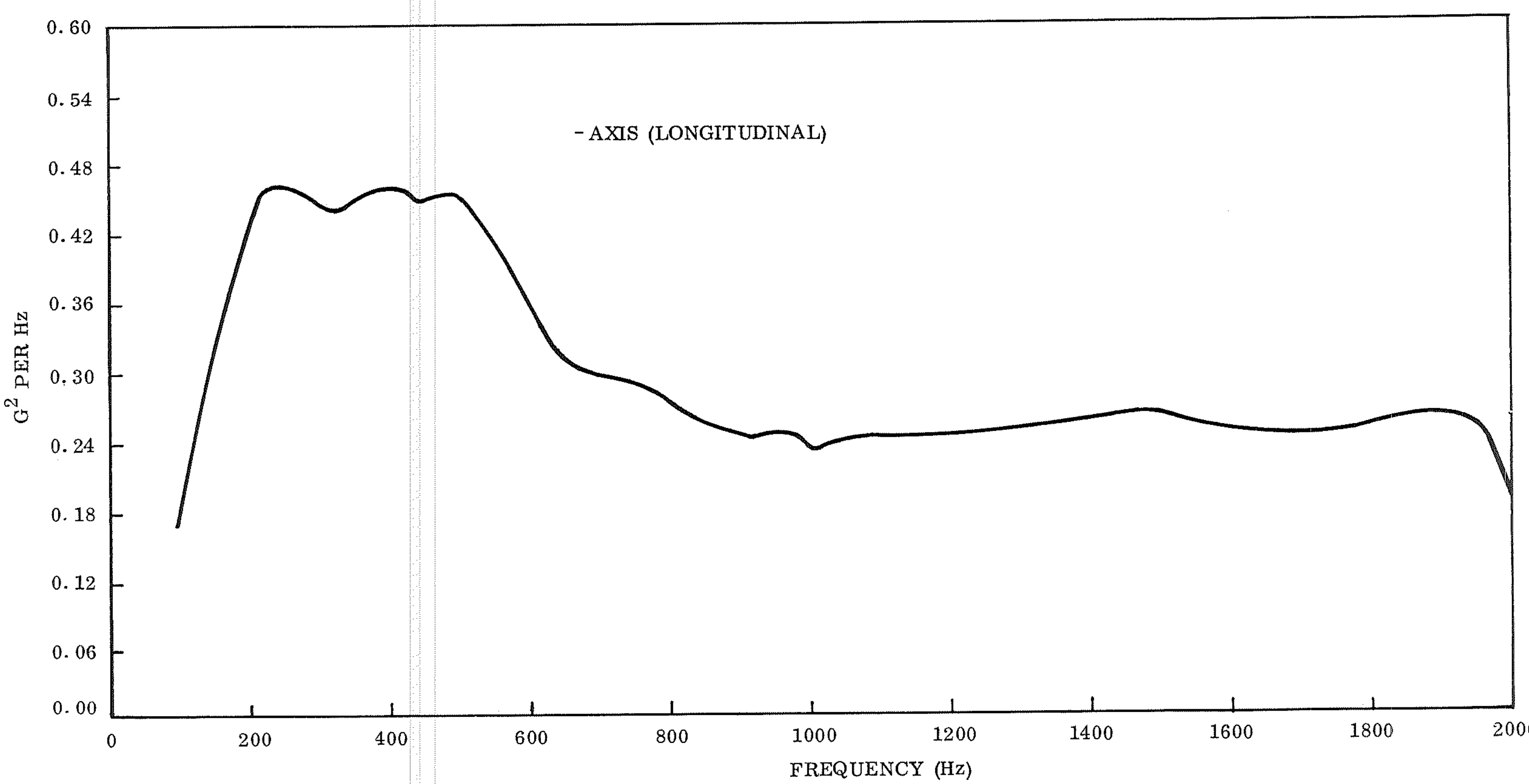


Figure 29 Vibration Test Trace (Random)

Both types of tablets survived the vibration test without any appreciable damage. Typical examples of both types of tablets after vibration are shown in Figure 30 with the coated pellets appearing in the top of the picture. The slight damage present differed for each type of pellet and therefore, each type of tablet will be discussed separately.

Figure 31 shows typical coated tablets after the vibration test. The dust and small chips shown in the picture are the total amount which was present in the container. Figure 32 shows an enlarged view of the same pellets. They are arranged by degree of damage, with those at the top the least damaged and those at the bottom, the most damaged. The damage consisted of a slight discoloration and scuffing of the surface coating and occasional slight chipping. At least 95% of the total number of tablets had very light or no damage and were similar in condition to those in the top two rows. The tablets in the bottom three rows are the worst tablets which could be found. The chipped tablets in the bottom row were the only ones damaged in this manner. It was noted that the more severely damaged pellets came from the bottom of the can.

The condition of the uncoated tablets after vibration is shown in Figure 33. Almost no powder or dust was observed in the container and the tablets were damaged only in that the edges were slightly roughened around the mold mark. Tablets at the bottom of the container appeared slightly more damaged than the others.

Other than slight surface roughening or scuffing, the majority of both types of pellets withstood the vibration environment without any damage. In addition, since the most severely damaged pellets were at the bottom of the can, this was most likely caused by the slight can-bottom resonance which was observed during the test.

Feeder mechanism development test.- This test was conducted to gain engineering insight into the problems of designing a bulk storage/discrete dispensing feeder mechanism. In this test, a prototype food tablet dispensing mechanism (without the lip device mechanism) was installed in a transparent canister, permitting direct observation of the tablet activity (see Figure 34). The cycle time was adjusted to exactly 5 seconds and the tablet velocity was computed by observation of its trajectory.

All the mechanical parts assembled and operated as expected, except for the tablet ejection rod (see Figure 35), which lacked smoothness running through the ball bushings. This condition was corrected by re-making the part from "Thomson 60 Case" shafting.

A tendency for the tablets to locally "bridge" a cup of the index wheel, around the inside diameter of the transparent canister, was eliminated by bonding a small rubber strip, 0.080" thick, to the canister interior. This ridge caused the tablets to rotate, collapsing the bridge.

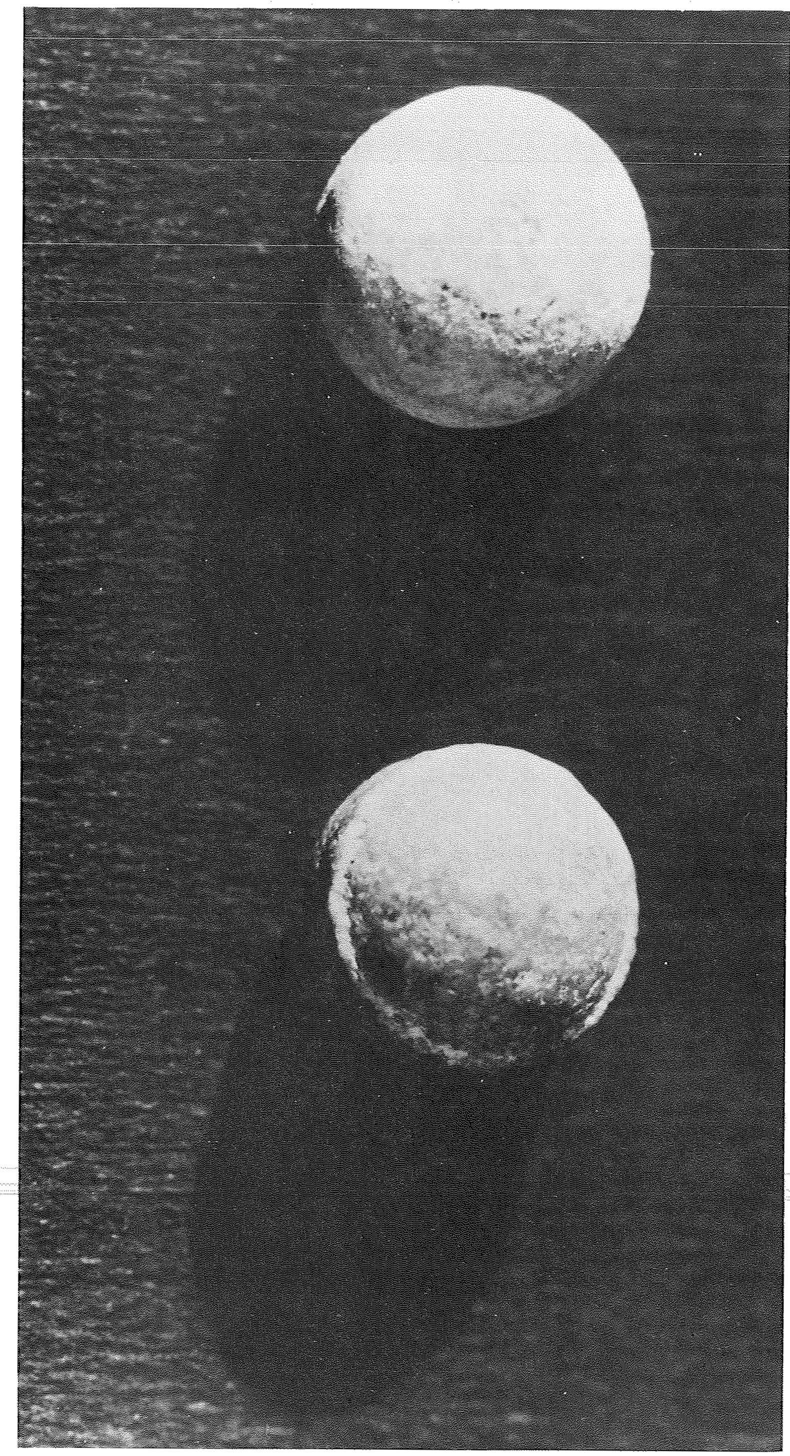


Figure 30 Tablets After Vibration Tests

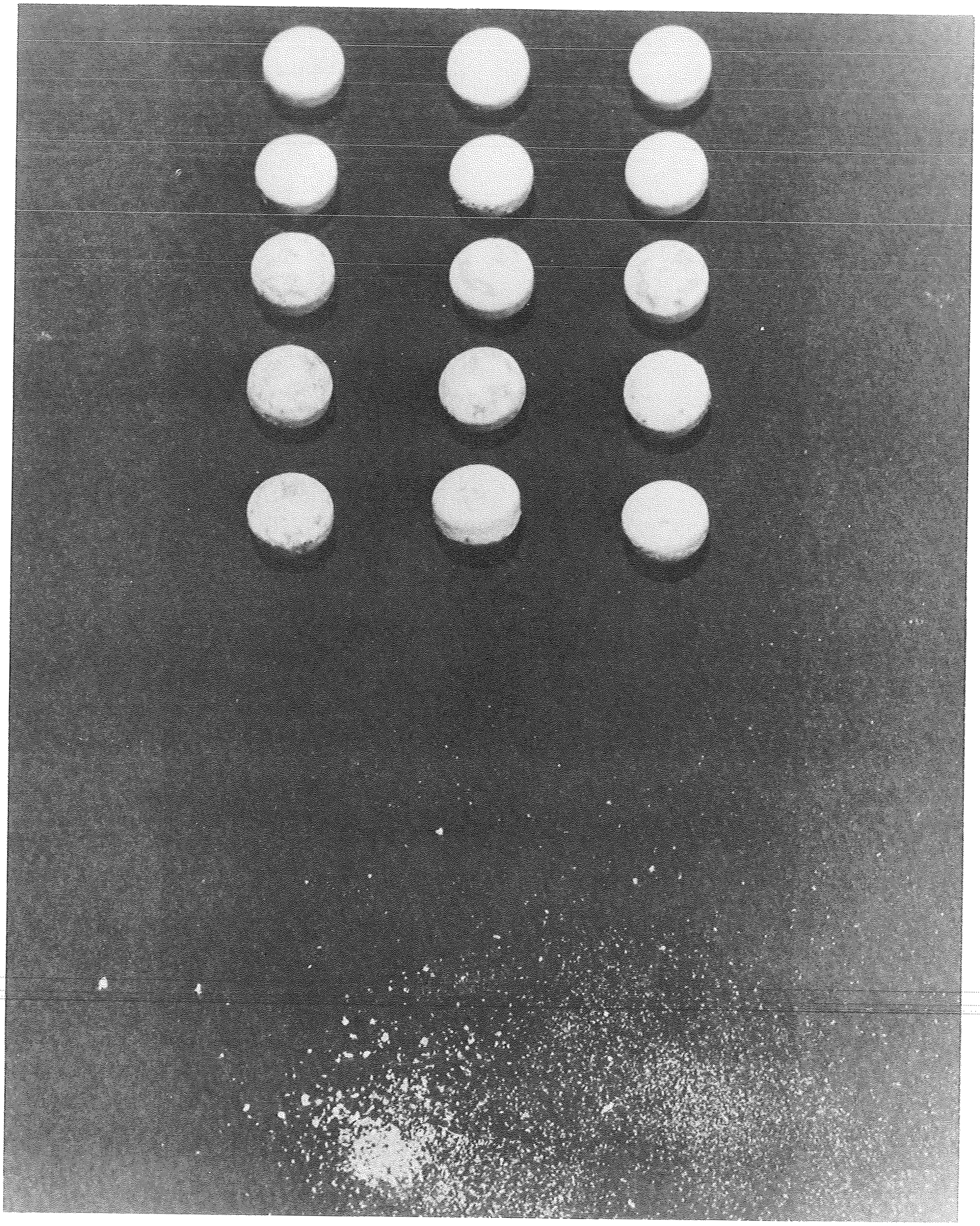


Figure 31 Coated Tablets After Vibration Tests

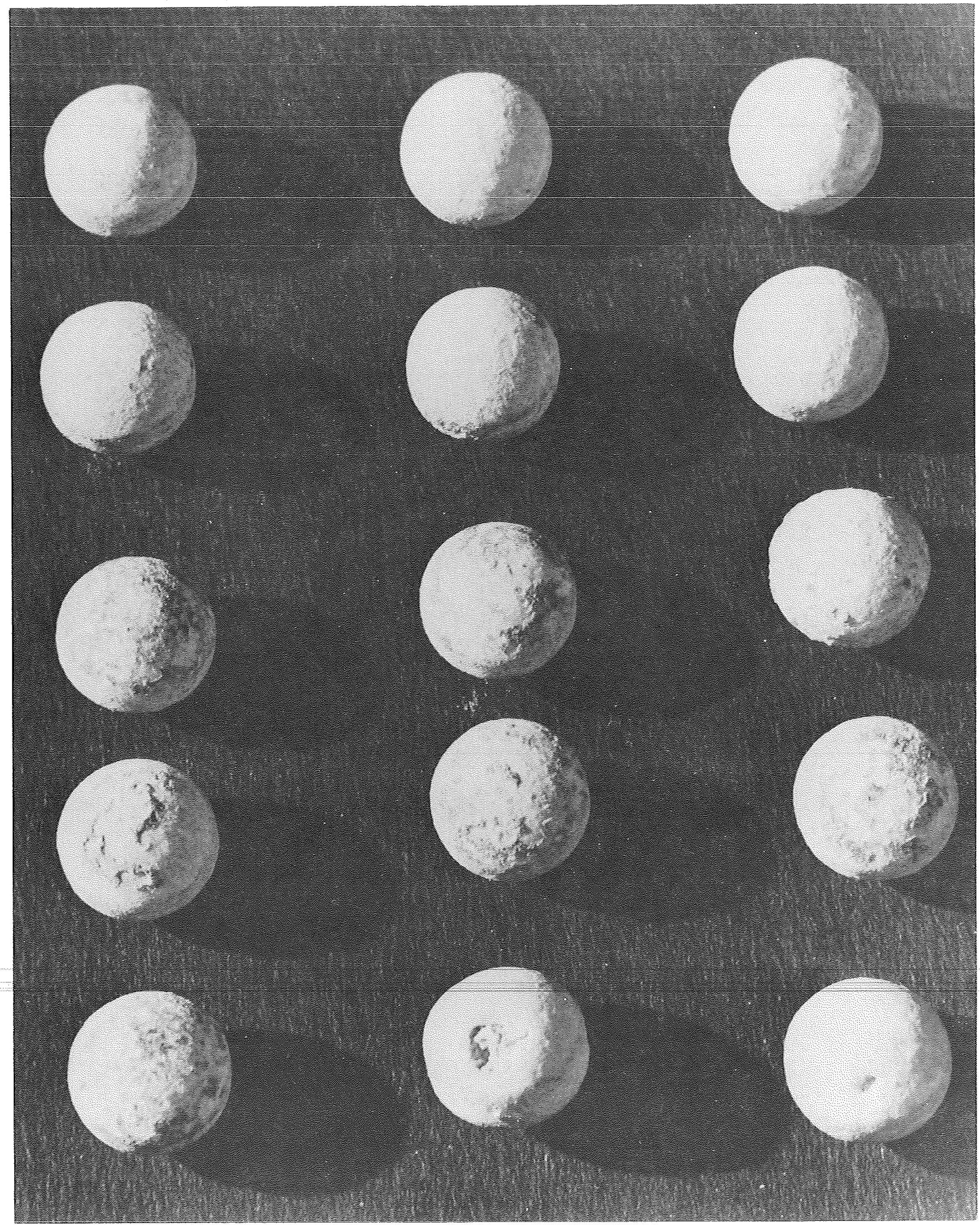


Figure 32 Enlarged View of Coated Tablets

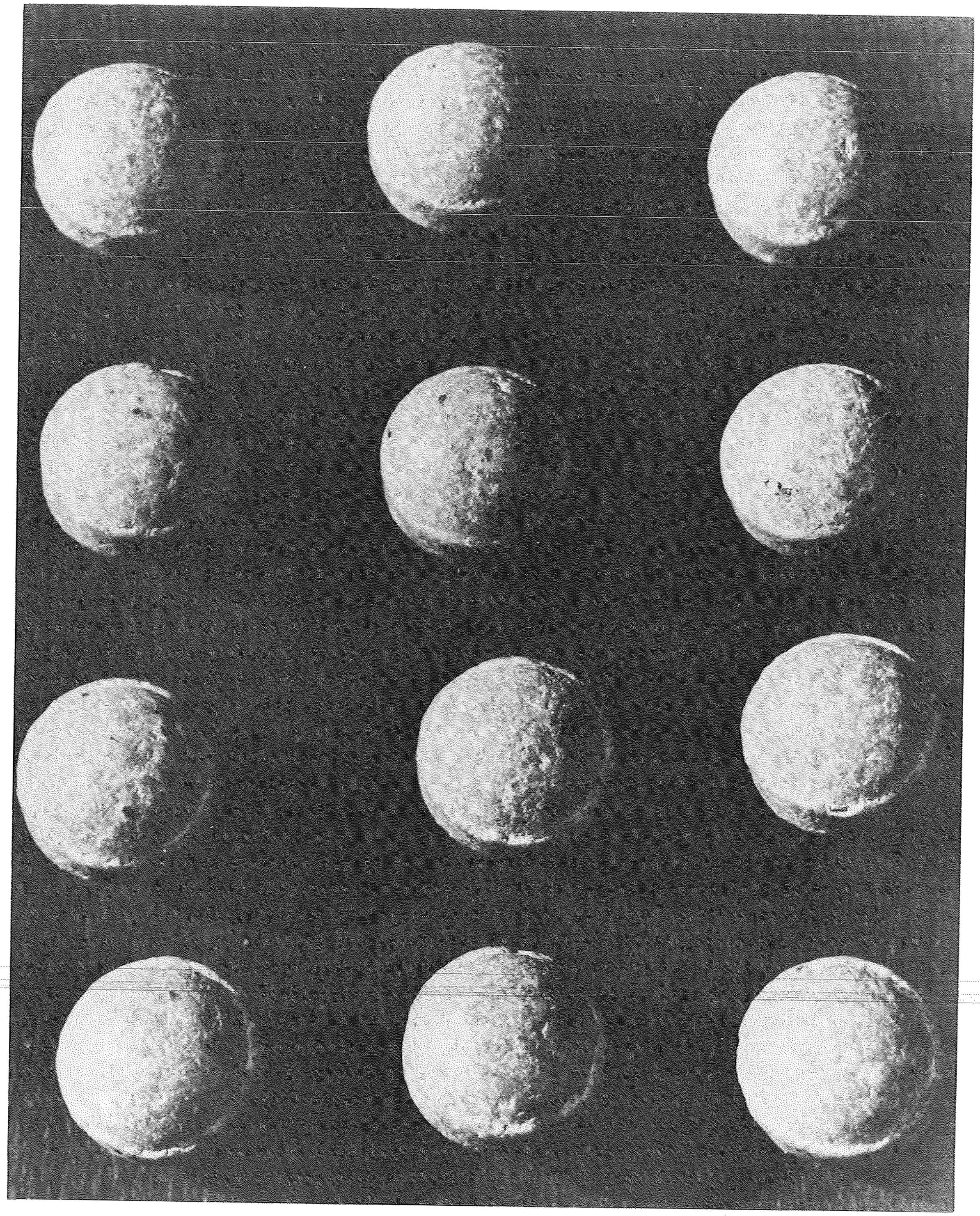


Figure 33 Enlarged View of Uncoated Tablets
After Vibration Tests

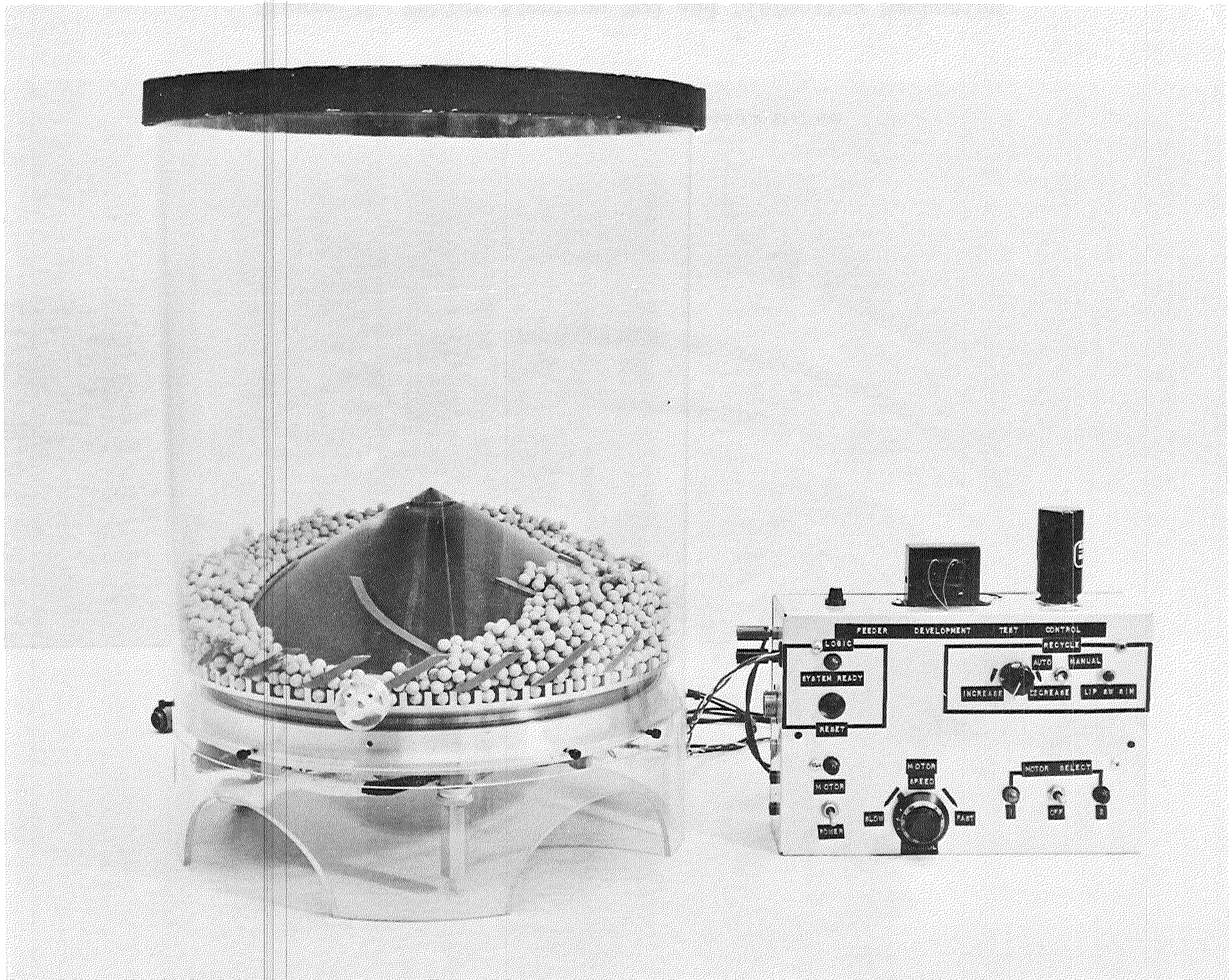


Figure 34 Development Test Feeder and Control Unit

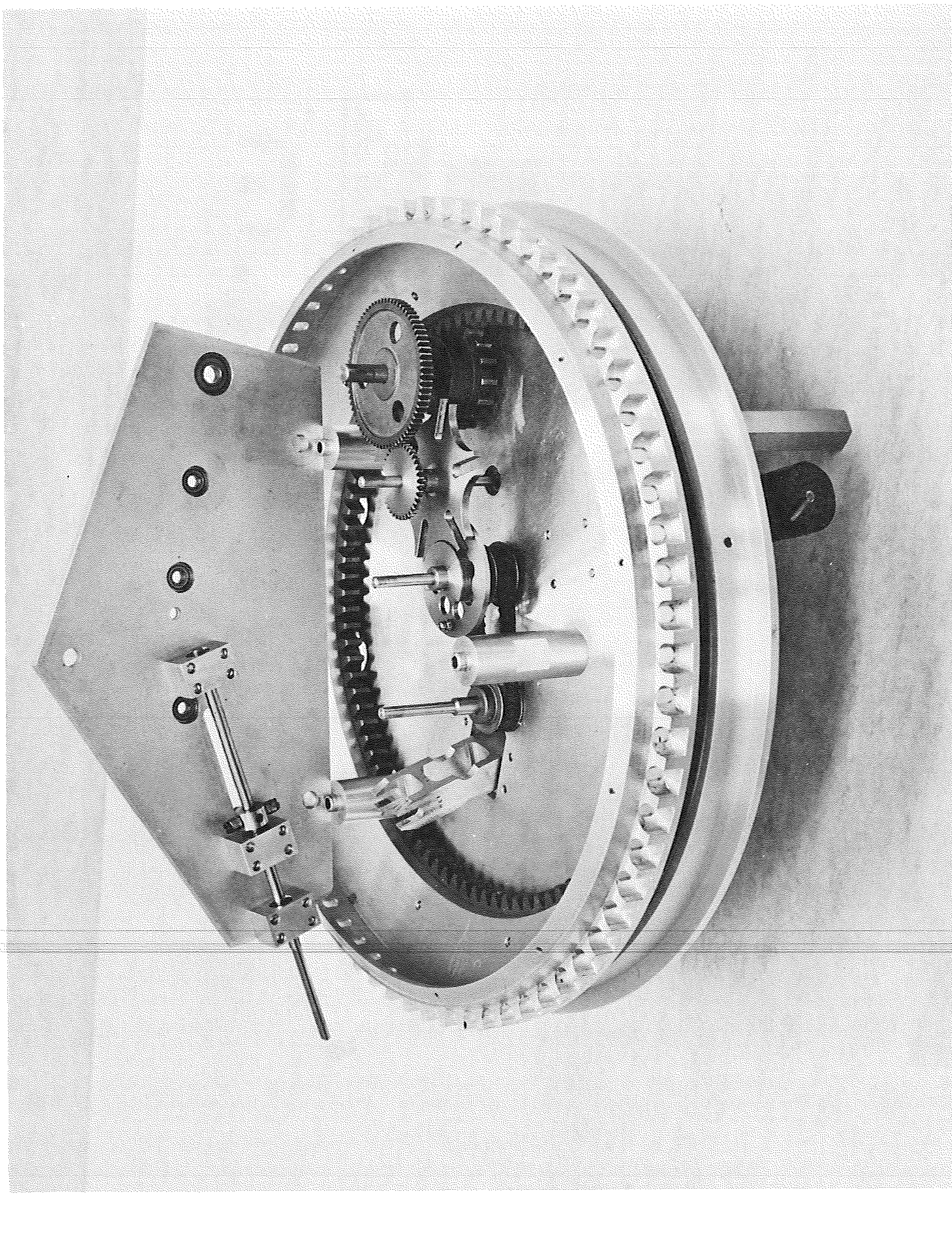


Figure 35 Tablet Ejection Rod and Dispensing Mechanism

The cups in the index wheel were found to be larger than necessary. The index wheel was machined to a new outer profile which provided that the cups may contain only one tablet. Using the previously mentioned rubber strip to agitate the tablets, the cups were always refilled in the first three stations after the dispensing station. There was no creation of "dust" due to agitation and movement of the food tablets.

A "brow" piece (See Figure 36) was installed over the dispensing station (cantilevered from the canister wall) to assure that only the one tablet, in the cup, would be acted upon by the ejection ram. This tablet was simply pushed through the one opening, the lip device port.

It was observed that the "brow" over the dispensing station served to generate voids which would not always collapse naturally. The rubber strip was placed an inch or so downstream from the dispensing station and situated diagonally to the movement of tablets.

The "brow" also prevented refilling of the cup prior to its being rotated past the lip device. It had been found that a tablet might so position itself that rotating the index wheel required shearing a tablet which was partly in the cup and partly in the lip device port. The "brow" eliminated this problem.

After the use of the "brow" piece was instituted, it was found that the "brow" itself would occasionally shear a tablet. The supply of tablets had become contaminated with partial tablets, due largely to the trial of various tablet agitation schemes. It was found that a half-tablet in the bottom of a cup would raise the adjacent tablet to a position where it was sheared by the "brow" piece, creating two additional half-tablets. The two half-tablets which remained in the cup would then be pushed into the lip device. The remaining half-tablet would proceed along in the tablet stream until it eventually entered a loading cup, usually falling to the bottom. Concern was felt that a progression of tablet cleavages might eventually cause all the cups of the index wheel to be "contaminated" with partial tablets and crumbs, which would be wholly undesirable.

A test was contrived in which 10 successive cups were each charged with a half-tablet and subsequently had whole tablets spilled into them. The index wheel was then driven through some 240 cycles, causing each of these cups to pass the"brow" piece three times. It was found that the cups were self-cleaning. In succeeding passages of the "brow", the whole tablet was either lifted over the brow, or forced under it while the ram continued to eject the residual from the previous breakages. The conclusion is that contamination by partial tablets could be tolerated and that only rarely might the primate be delivered a partial tablet. It was recommended, however, that care be taken to inspect the tablets to be placed in the feeder, and to avoid dumping the tablets from excessive heights. The feeder was also provided with a window in the side wall where the tablet condition and the loading cups could be monitored.

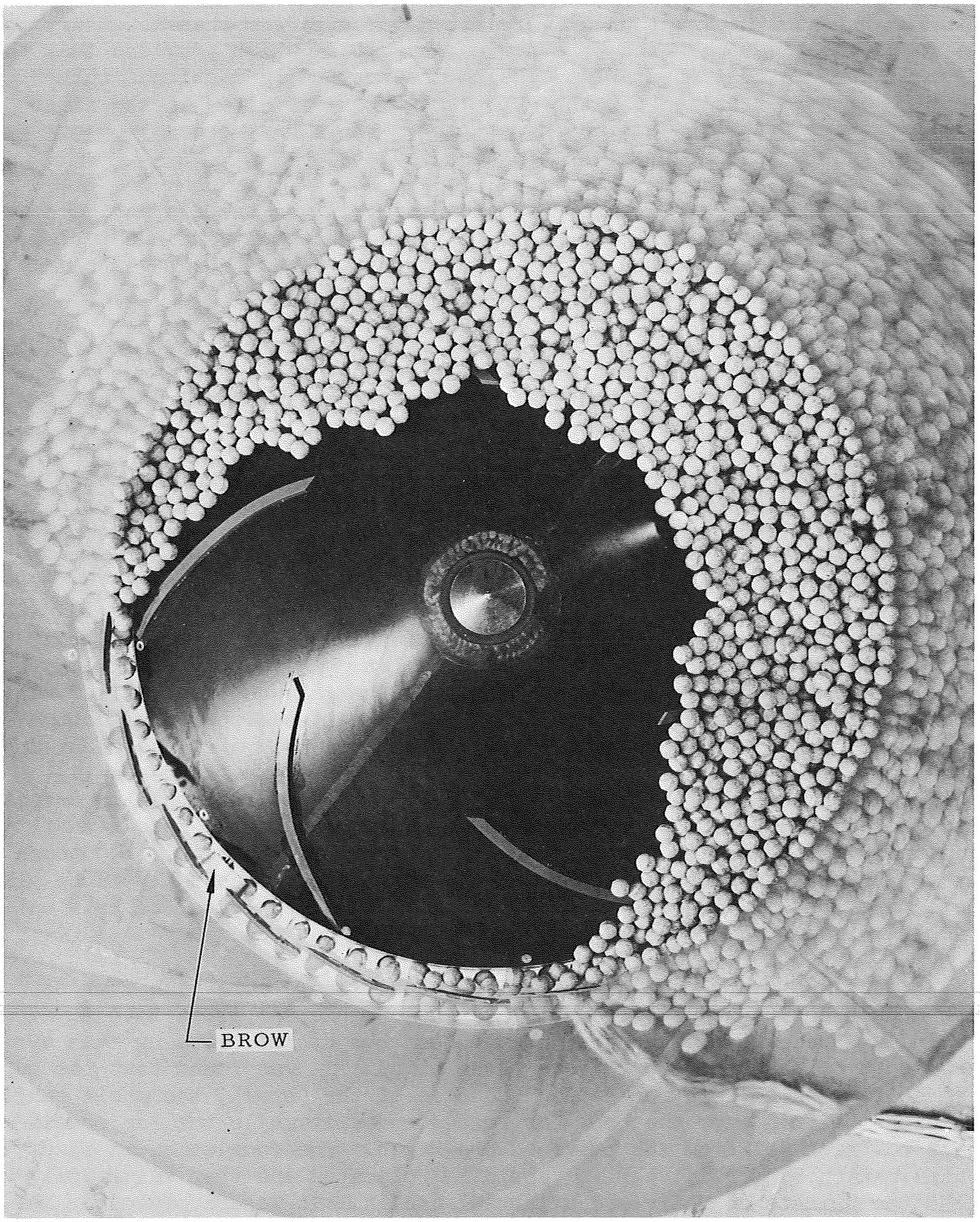


Figure 36 Tablet Dispensing Station Showing "Brow" Piece

As a consequence of the possible tablet shearing activity, a shear test apparatus was built (Figure 37) so that the strength of the tablets could be measured. The tablet is snugly fitted (0.001" loose) halfway into the block and the hole in the inner sheet surrounds the exposed half. Shear was measured directly at 25 to 34 lbs, with 27 lbs being an average value. The drive system in the feeder provides a tangential force well over 200 lbs at the outer diameter of the index wheel and therefore cannot be jammed by a tablet in shear.

The tablet ejection rod traverses 2.16" in the allowed time, positively displacing the tablet through the entire length of the lip device. The delivery time was 0.75 second when the cycle length was 5 seconds. The action was smooth and the tablet acceleration was essentially constant. Tablet behavior was quite repeatable. The face cam, lever, ball bushings, needle bearings and push rod behavior was entirely satisfactory.

The average tablet velocity at the moment of discharge from the lip device was 16.7 cm/sec (15.0 cm/sec specified maximum). The range of velocity in 37 events, varied from 14.61 cm/sec to 17.93 cm/sec. Figure 38 shows the test setup and Figure 39 shows the impact distribution as recorded in the testing. It is believed that the non-spherical tablet tumbles through the mouthpiece tube in a random manner which accounts for much of the variation recorded.

The tendency for tablets to bridge locally was previously discussed. In the course of correcting this tendency, additional low-height agitation ridges, in the form of spiroid ridges on the conical element of the index wheel, and a series of angular pads on the feeder wall were added. These devices generated a "cup filling vector" which never failed to provide cup-loading when the canister was upright or on its side. One series of tests involved tipping the feeder over sideways 100° from its normal upright position such that the storage volume was "downhill" 10 degrees of arc. Then at various "clock" positions of the ejection tube, the mechanism was operated and found to be fully successful through numerous trials at each position.

The intermittent motion devices were satisfactory. The face cam groove (see Figure 40) which drives the ejection ram lever was slightly loose on the ball end of the lever. With amplification, the ejection ram had about 0.040" of end play. During operation, this variable was of no consequence. The Geneva lock mechanism worked well at all times, though it was of a light duty type. The final design has a much stronger mechanism mounted on 3/8" diameter shafts vs. the 1/4" diameter shafts in the test model. This permits a much higher torque through the drive train.

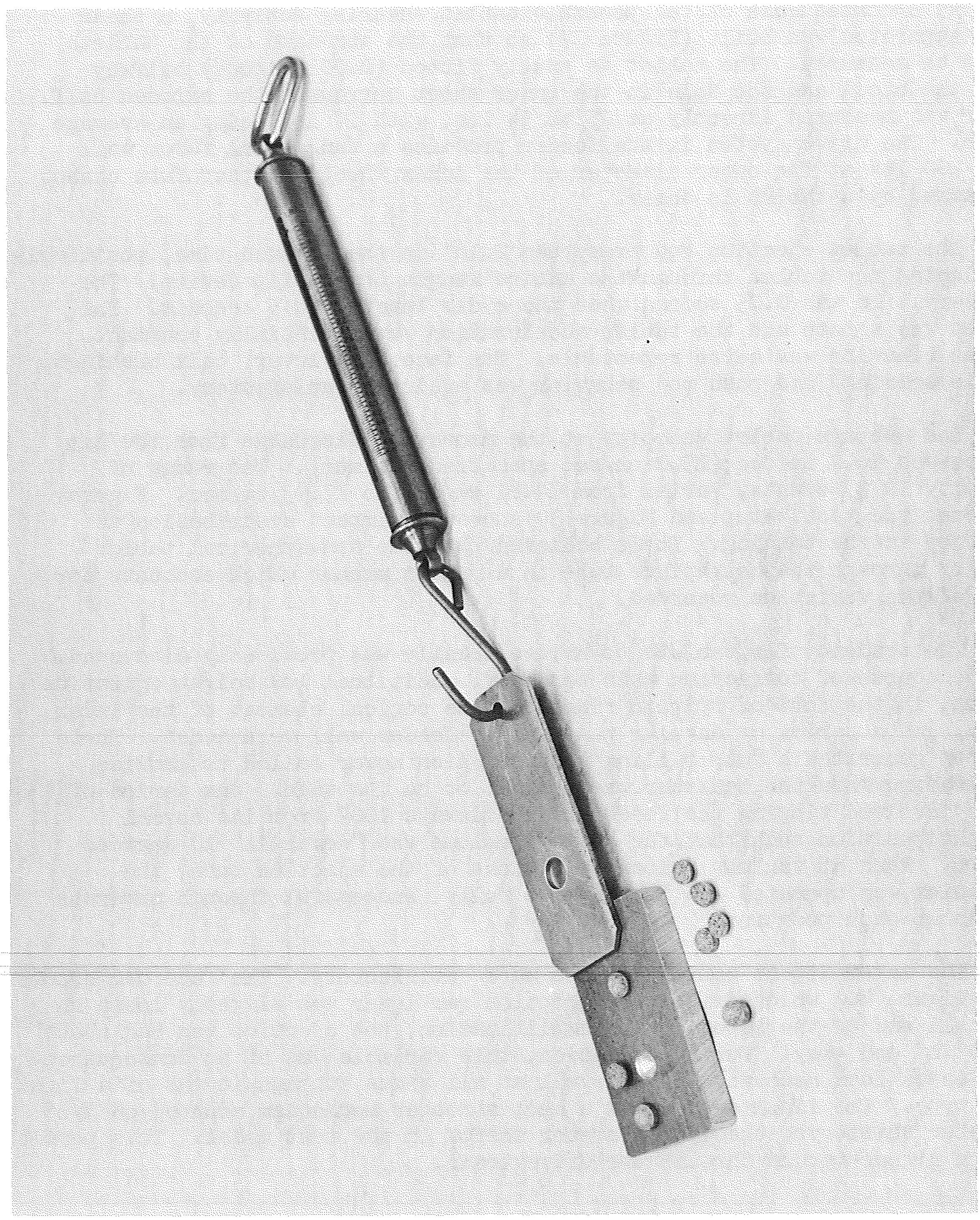
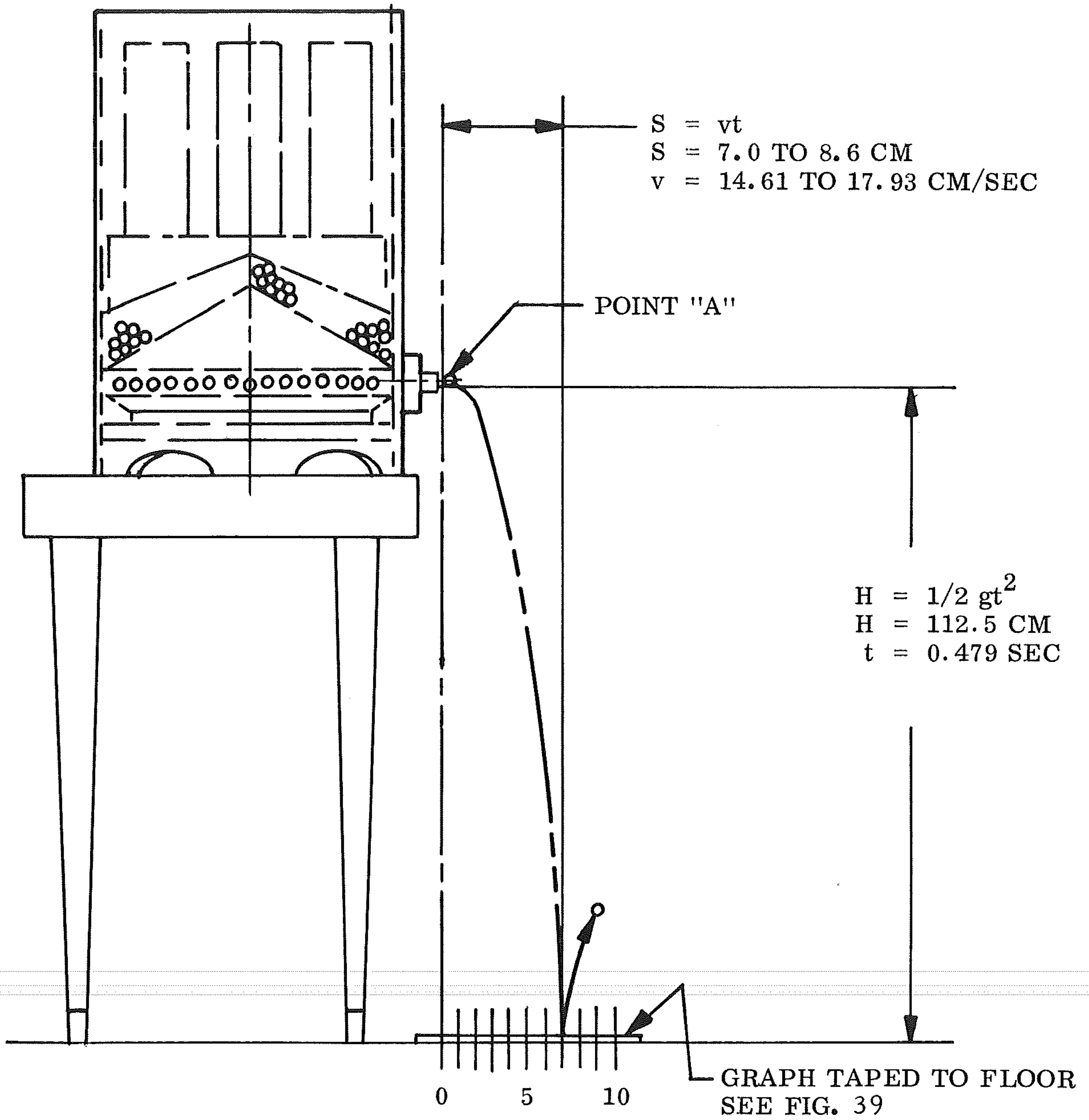


Figure 37 Shear Test Apparatus



NOTES:

CYCLE TIME: 5 SEC
ELAPSED TIME TO POINT "A": 0.75 SEC

Figure 38 Tablet Velocity Test Setup

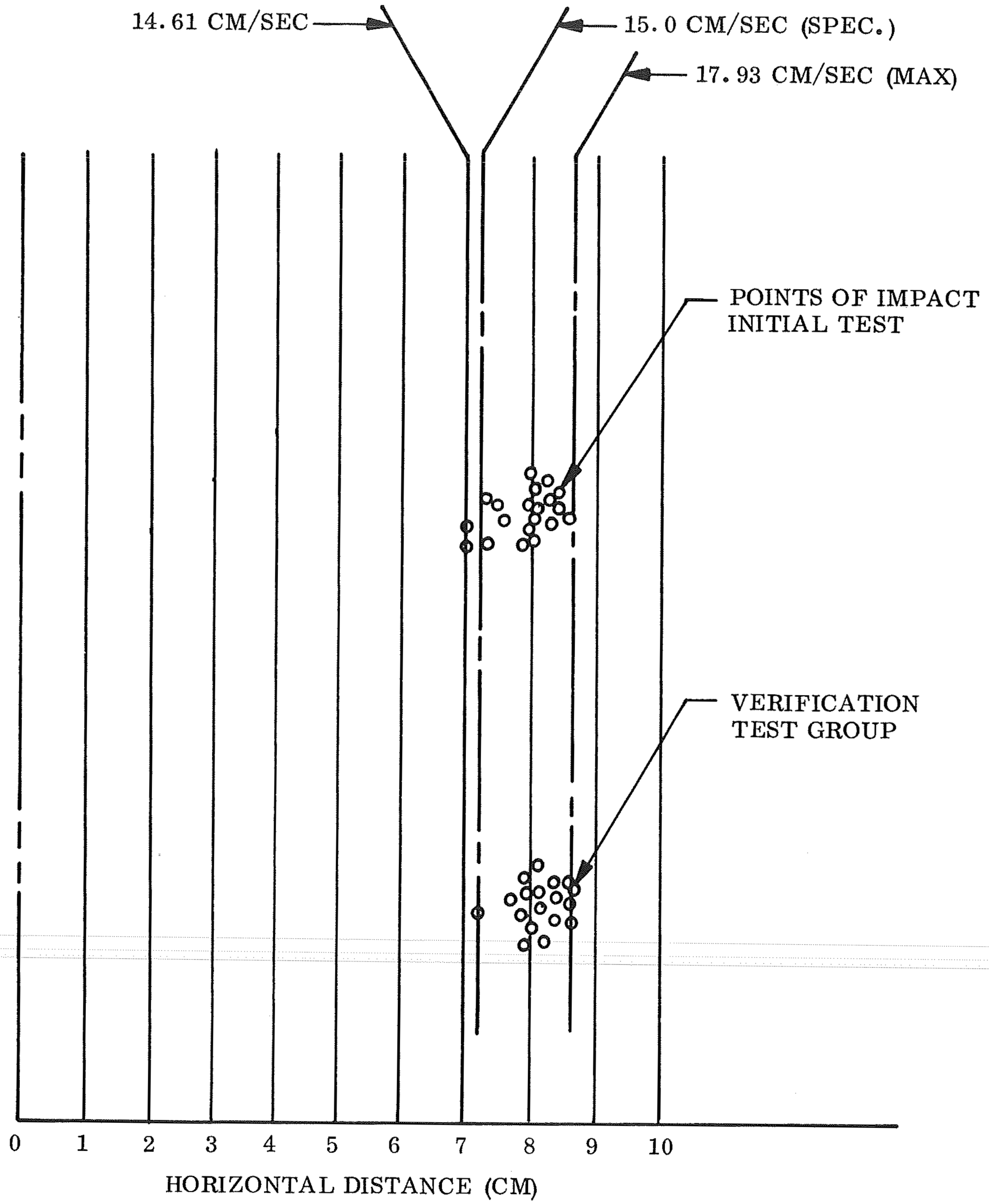


Figure 39 Tablet Velocity Test Results

The single-turn shutoff cam (see Figure 40) which operates two microswitches (one redundant) was the object of some experimentation. The depression into which the leaf element rollers "drop", closing the switch, required sufficient depth that the switch authoritatively pulses the electronic logic system. It was also desirable that the dwell of the rollers in this depression be minimized to the point that the rollers would climb out of the depression during the coastdown of the drive train. These requirements are due to electrical transients arising from the internal mechanical rebound of the microswitch during its actuation phases.

The hermetically sealed microswitches used were Minneapolis-Honeywell Part No. 1HM1. The switch has an external lever which is operated by a leaf/roller. Although these switches require care in mounting and adjusting, their usage is retained because of their hermetically sealed characteristic.

The gearing, shafting and bearings were satisfactory, provided that all gearing, cams, and shaft collars were pinned or very securely clamped. When properly assembled, the risk of phase shifting of the drive components is negligible. It was found that the index wheel had approximately 0.030" of "backlash" at the outside diameter. While the amount could be tolerated, it was found that it could be compensated for at assembly since the index wheel always rotated the same direction, and is experiencing drag from the tablets. The push rod can then be aligned with the center of the loading cup as it would be in actual use. The amount of "backlash" noted is entirely consistent with the use of commercial gears.

The one-way roller clutches (see Figure 40 and 41) were entirely satisfactory. The driven shaft deviated from that recommended as follows: The diameter was reduced empirically from 0.5000/0.4997" to 0.4990/0.4985" to reduce drag in the slippage direction. Due to a vendor error in supplying material (contrary to their certification), the shaft hardness was R_c 38 (Rockwell C Scale) instead of the R_c 58 desired. During testing, no shaft degradation was observed, which leads to the conclusion that precipitation hardening stainless steel with R_c 44 hardness would be adequate and be much easier to produce. The required torque levels are well below the 80 in-lb rating of the Torrington design.

Torque requirements were determined by exchanging a torque wrench drive assembly for a motor drive. With 15 lbs of tablets on the index wheel, the peak torque (during indexing) was about 1.5 in-lb. This load is equivalent to the proposed pressure plate spring force (see Figure 42). A "proof test" was made by situating 185 lb load onto a pressure plate, which was bearing uniformly on the 15 lb of tablets. The peak torque observed was 15 in-lb. During these tests, all tablet agitation strips shown were in use. The test was not a completely faithful construction of the flight situation in that relatively few tablets were available to cause "rubbing" against the canister wall. The anticipated "worst load" during the pre-launch mode of flight hardware is 158 lb of which 140 lb is food tablets.

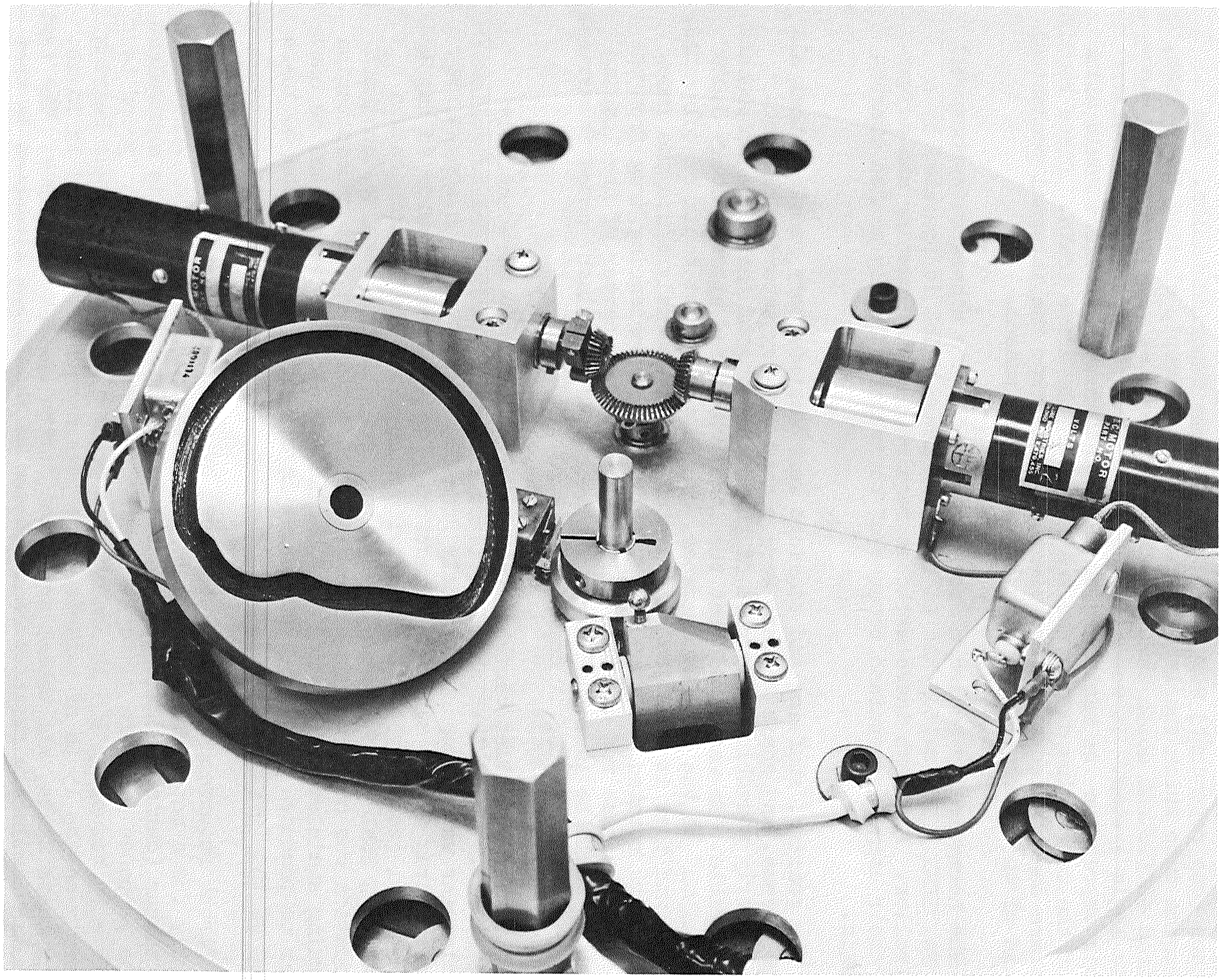


Figure 40 Bottom View of Feeder Mechanism Partly Disassembled

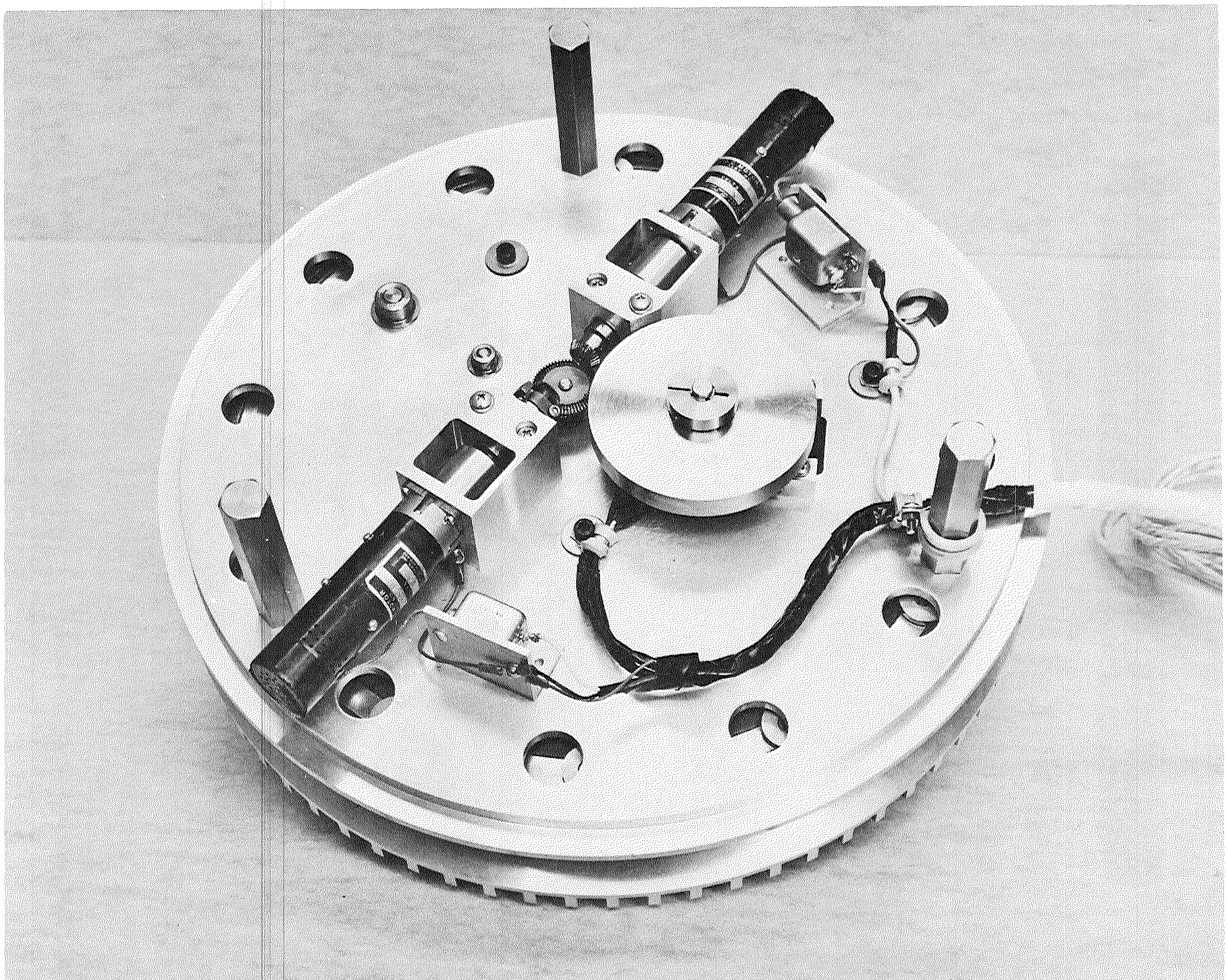


Figure 41 Bottom View of Feeder Mechanism Assembled

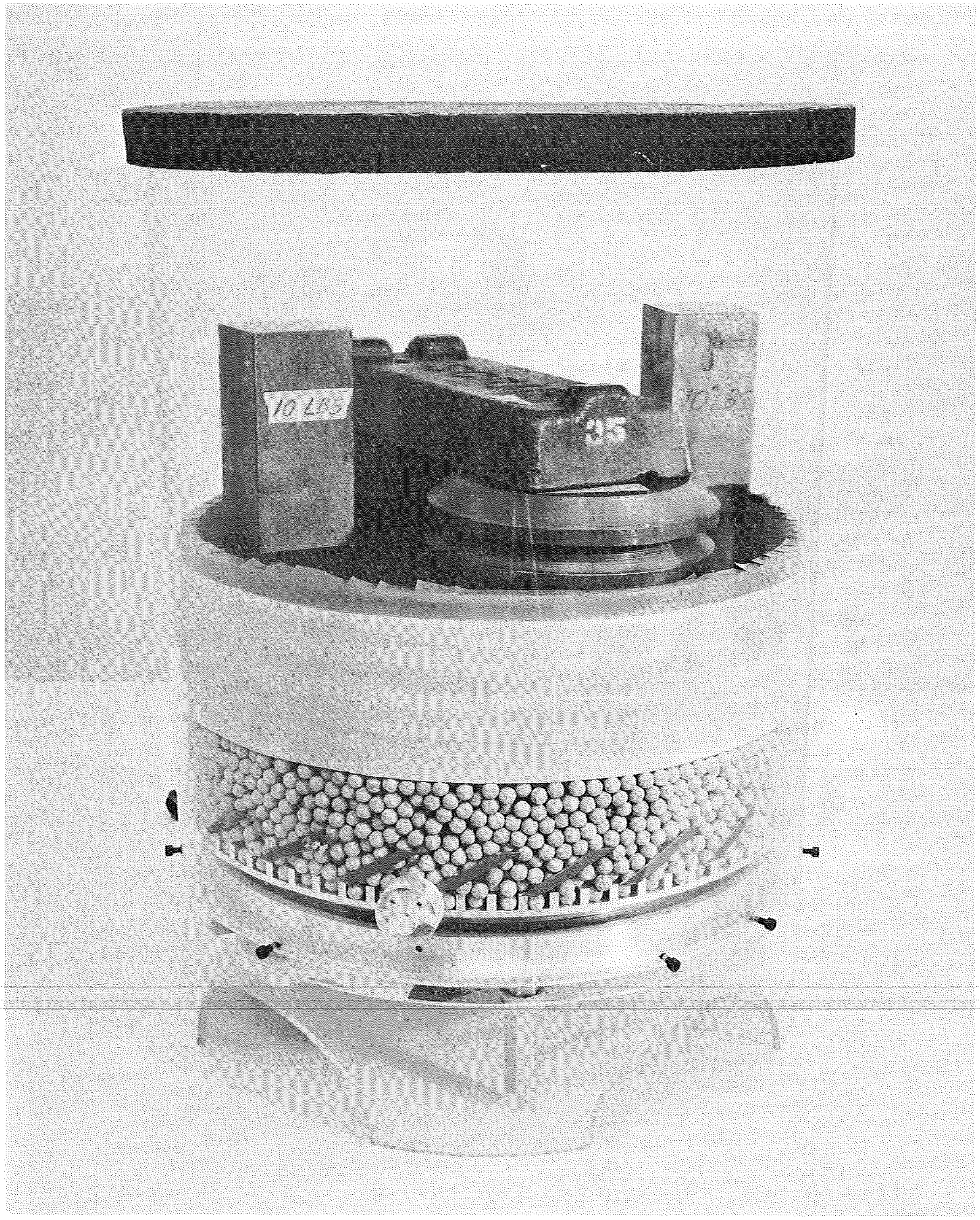


Figure 42 Feeder Pressure Plate Installed and Loaded

The gearmotors for the final design are rated at 33 in-lb at the continuous speed of 26 rpm. Speed will reduce gradually to about 20 rpm while approaching the stall torque rating of 154 in-lb, should the occasion ever arise. The surplus DC type gearmotors used in the development testing were found to stall at less than 2 in lb when adjusted to 24 rpm. It is noted here, because this small torque was used extensively in the development testing.

The prototype mechanism, shown in Figures 43 and 44, was an extremely valuable tool in design verification.

The slightly higher tablet ejection velocity was evaluated subjectively by persons accepting the tablets as the primates would. The velocity was considered acceptable and no corrective action was taken with regard to this matter, as a rather sophisticated cam and lever analysis is involved.

Operation of the mechanism on its side provided some confidence in the design validity for zero-g operation, while operation fully inverted imposes a condition which is unrealistic.

Behavioral task panel development test.- Several functional development mockups of the lever, microswitch, lever return spring, and moisture seal were fabricated and tested. The goal of these tests was to design a combination of the above elements which would meet the 3 oz actuation force required, still have a positive lever return, and provide an adequate seal, all within the lever actuation travel of 1/4 inch. Testing of these mockups consisted of operation of the above components and measuring the force required to operate the lever through its full travel. The test hardware was then modified and checked again until the device met the design requirements. The final lever switch configuration was designed using the proven concepts evolving from the development model.

Television system development test.- Development testing for the TV subsystem was extensive and used to determine mounting locations, viewing angles, picture quality and operational limits of the pan and tilt mechanism. These tests were conducted over a period of several months so that as other systems were designed, they could be added to the development mockup to check operational limits of the TV system in regard to pan and tilt and viewing angles.

The first series of tests were designed to help determine the type of TV camera to be purchased, what lens system was best suited to the TFDM, and to define an envelope at the top of the cage assembly for the TV system to occupy.

A foam core mockup of the cage envelope was fabricated with behavioral task panel levers, and the food and water lip device located on the cage interior in the proper position. A TV test pattern was placed on the cage floor for use in determining the performance of the TV camera system in terms of clarity and resolution. This test also revealed how much of the cage interior would be visible, how much scanning would be required to provide adequate coverage, and the effects of lighting levels relative to picture quality.

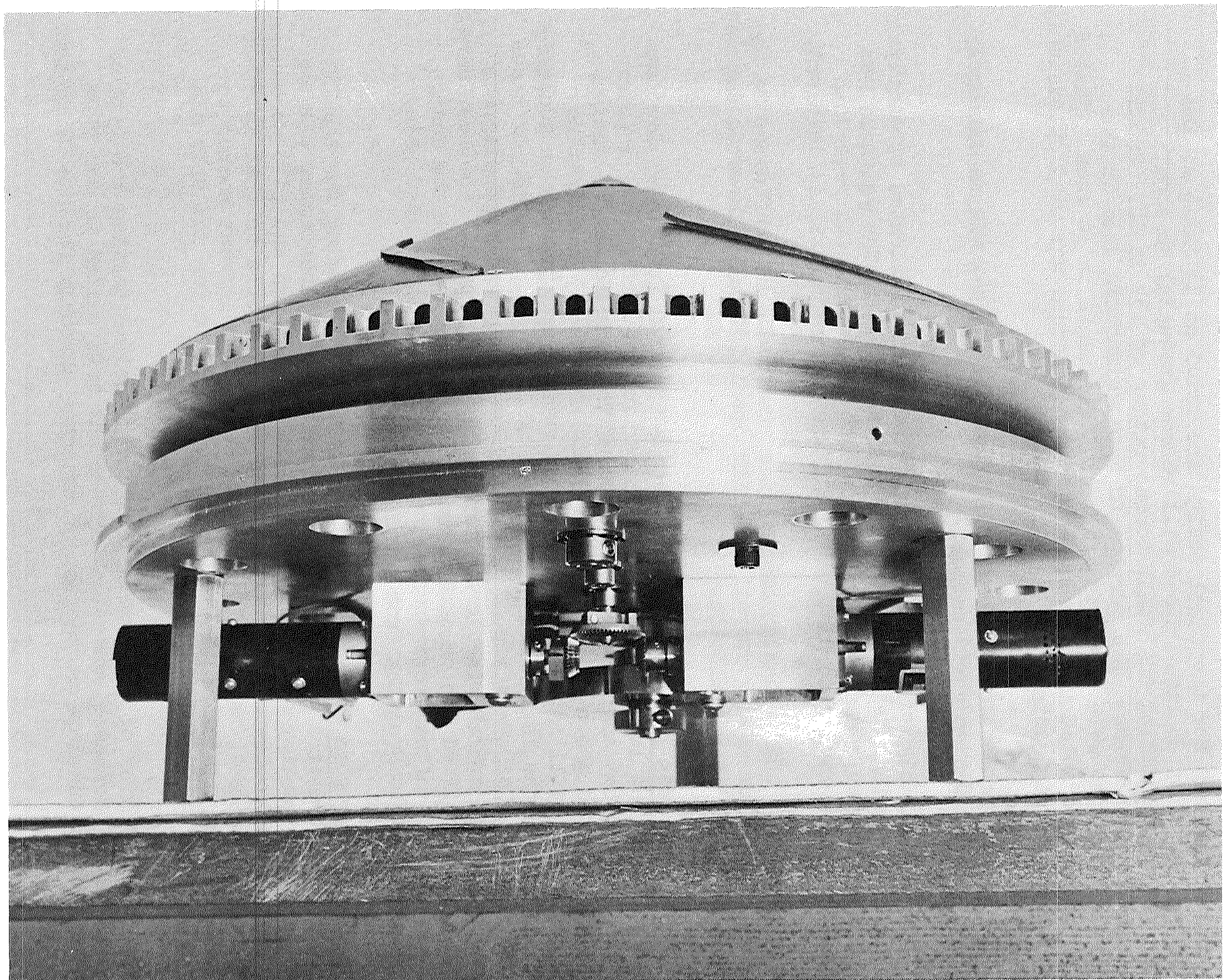


Figure 43 Assembled Feeder Mechanism Sideview

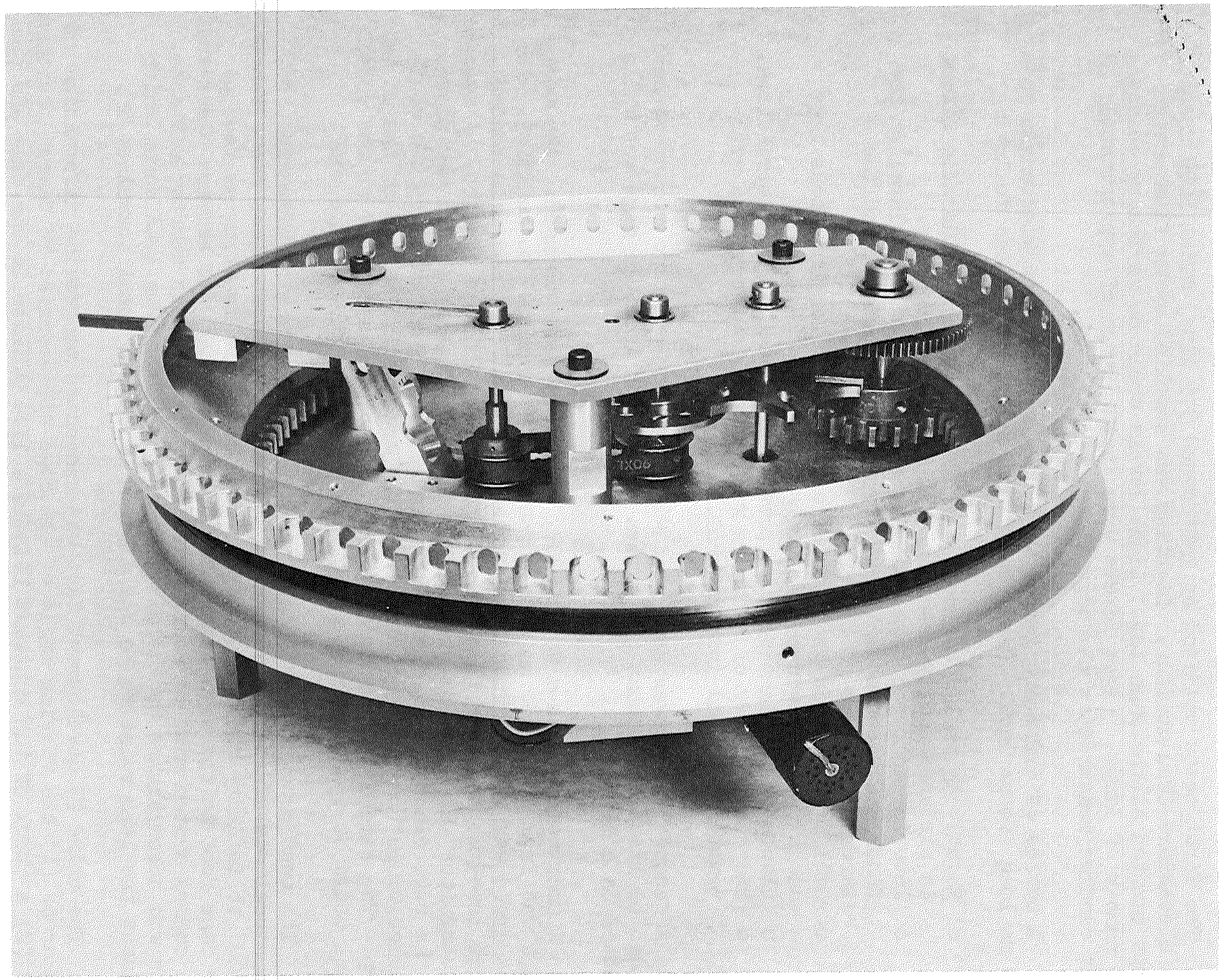


Figure 44 Assembled Feeder Mechanism Sideview With Cone Removed

The first tests utilized an LMSC owned 945 line, model 3000 camera and a standard Cohu monitor. Lighting was supplied using fluorescent lamps mounted at the cage top. Light levels could be varied by changing the number of lamps. Light levels were in the range of approximately 25 foot candles measured at the cage floor.

A series of different lenses were used ranging from wide angle to a 150 mm long focus lens. Results of this test revealed the following:

- o Relatively small changes in light level have considerable effect in picture quality when high resolution is required.
- o Interior color of cage wall has an effect on light level at the floor and picture contrast between viewing object and the interior surface of the cage.
- o 0.010" resolution is possible with the 150 mm long-focus lens and a 945 line video system.
- o Placement of lighting must provide even cage light distribution.
- o The desirability of a camera with a zoom lens equipped with remote focus and iris control.

A second TV test was conducted with the complete cage mockup assembly placed on its side so that the camera could look from the cage top while mounted on a tripod.

A Cohu camera with a Model 2307, 10:1 zoom lens was used. The zoom range was from 15 to 150 mm with a focus range from 60" to infinity. The lens speed was f/2.8. This lens system had both focus and iris control. Light level at the cage floor was approximately 25 foot candles. A standard Cohu monitor was used for picture viewing and TV test pattern was placed on the cage floor for resolution determination. The camera system would resolve 0.010" on the cage floor with the zoom at 150 mm and at the 15 mm stop. The cage floor, behavioral task levers, and about 1/3 of the social panel could be seen. The camera system was fixed at the cage roof.

The test proved satisfactory, meeting performance requirements, but did reveal one additional design requirement. Since the lens focus range is 60" to infinity and the distance from the camera mounting surface on the cage roof to the cage floor is approximately 50", it becomes clear that the camera system must be modified to focus within this shorter distance. This was accomplished by the addition of a motor-driven lead screw which adjusts the lens relative to the vidicon through a total travel of 1".

The third TV development test was conducted to provide information in two areas (1) the viewing angle of the cage side-mounted TV camera position, and (2) a check of the contrast between a live primate in the cage and the cage wall. To accomplish this test, the cage liner retraction test mockup was used. The cage liner was coated with Kymar Fluoropan (capri blue) and installed in the mockup. The side TV port was selected for this viewing test to verify the lens field of view. A Cohu camera fitted with the wide-angle Angenieux f/1.8, 5.9 mm lens. A standard Cohu monitor was used.

The primate was placed in the cage and the contrast between the primate and the cage liner studied. Side TV field of view was satisfactory, showing all of the social window, food and water lip device, behavioral task panel, exerciser, and if in the down position, about half of the cage floor. It was felt that the contrast between the primate and the cage liner could be improved if the blue coating was about 50% lighter in color. The vendor was contacted and a new shade was developed (Chase CK 205 light blue). The primate was kept in the cage system for several days to see if he could chip, peel, or scratch the Kymar coating. This test revealed that only if the primate could get his teeth on each side of the liner could he scratch off the coating.

The cage liner development mockup was cycled manually many times to observe the effect of rolling the 0.016" liner on the 5" dia take-up spool with the Kymar coating on the interior surface of the liner. The Kymar coating did not crack or peel, and proved to be a tough durable finish.

Magnetic activity monitor development test.- This development test was to determine the sensitivity of the magnetic field sensor coils mounted to the cage exterior in conjunction with a magnet of a type to be implanted into the primate. This test also finalized the location of the coils on the cage exterior.

The two pickup coils were set 36.0 inches apart, simulating the spacing of the coils when mounted to the cage assembly. Magnets of various strengths were moved about in order to determine the sensitivity of the circuit for digital output response, and the strength of the magnet required for implantation in the primate determined.

This test indicated that a distance of 18.0 inches off the 36.0 centerline between the two pickup coils was the farthest that a group of four 1/4" x 1" Alnico 5 magnets would work reliably. It was noted that the analog output varied around zero volts. This required a change to perform at 2.5 v ± 2.5v. All four sensor inputs were demonstrated to work satisfactory.

Photocell activity monitor development test.- The breadboard of the photocell circuit was demonstrated by connecting a Clairex CL 705 HL photoresistor to the input side of the photo cell circuit. The digital output signal was observed on an oscilloscope. It was noted that the circuit reliably responded to interruptions in a small beam of light as well as to slight variations in dimmer ambient light. The photo-resistor used in the final configuration was changed to respond to the light spectrum resulting from inclusion of the infrared filter. Both digital outputs were satisfactorily demonstrated.

Biotelemetry antenna array development test.- It was realized early in the program that the biotelemetry antenna would be one of the more difficult design areas. The low level signal from the implant within the primate, the changing position of the primate in the cage relative to the antenna and the fact that the cage itself is a circular waveguide below cut-off frequency, all tend to complicate the problem.

In order to establish the orientation and number of antenna coils required for satisfactory reception, a series of tests were carried out using a Whittaker Type BT2 transmitter operating at 94.8 MHz and placed inside a steel cylinder approximately 23" in diameter and 32" in length. One end of the cylinder was closed with a metal cover, and the other end was left open.

A single-turn wire loop 5" in diameter was mounted inside the steel cylinder near the middle of one side, tuned to 94.8 MHz and matched to the input of a test receiver, J. W. Miller, Model 580.

By rotating the loop while the transmitter was moved around and turned inside the steel cylinder, it was found that the best results were obtained with the loop axis parallel to the axis of the cylinder, i.e., with coupling to Hz fields maximized.

It was next found that a rod of VHF-type ferrite with a single turn coil performed as well as the wire loop and that equivalent performance was obtained with the ferrite rod inside the steel cylinder or immediately outside an axial slot in the side of the cylinder.

When two magnetic dipoles, i.e., ferrite rods with single turn coils, were placed approximately 12-1/2" apart along one side of the steel cylinder, their outputs can be combined in a 3 db/90° directional coupler to provide a strong output when the transmitter is at any point of a cross section between the two magnetic dipoles or approximately 8" beyond one of them, except that some combinations of transmitter location and orientation result in zero received signal. However, these nulls are very sharp.

It was noticed that whenever the transmitter was less than 8-12" from the steel cylinder wall, the transmitter frequency was changed enough to cause loss of received signal. Retuning of the receiver was difficult because the transmitter frequency was sensitive to small movements and the AFC of this receiver could not operate on pulsed signals.

System Tests

The system test program for the TFDM was designed to test critical subsystems relative to end item performance. This system test, prior to acceptance test, would allow time for rework or adjustments to meet performance requirements.

Primate/Equipment/Interface/Test.- This test was planned to verify the compatibility between the primate and the interfacing equipment, such as the cage liner, social window bars, behavioral panel levers, and side TV camera port.

The TFDM basic structure, cage backup structure, cage liner less roll-up motor and clutch, behavioral task panel, waste management system dome, and the ground support dolly were assembled in a separate room within the manufacturing area. A temporary cage floor, cage roof, and waste collection system was fabricated and installed, completing the test assembly. A laboratory type feeder and drinking water bottle was added to the assembly. The test hardware configuration was the same as previously shown in Figure 1.

The government furnished primate, from the Naval Aerospace Medical Institute (NAMI) was visually checked prior to being placed into the cage. In this way any new cuts, scratches, or abrasions could be identified if caused by the cage or equipment during the test period.

Screens were placed over the social window and the side TV port, and the animal placed in the cage assembly. Since this test was conducted in a working area the primate had daily visual contact with people. During the night the primate was alone and the building lights turned off. All personnel entering the test room were required to wear face masks to reduce the animal's microbiological exposure. Animal well-being was observed twice each day by a qualified animal handler.

During the week-ends, with the exception of visits for the animal handler, the primate was alone. It was during this time and at night that the animal took the time to pick and chew on the hardware. It was noted that the primate thoroughly investigated his environment. While not trained to operate the behavioral program, he would periodically operate the task levers. Over the test period of approximately 30 days, the primate did not deform or damage any of the cage liner or structure. The behavioral task panel, with the exception of some dirt on the task levers, showed no signs of wear. The social window bars proved to be stiff enough to prevent animal escape (See Figure 45). The primate was not able to pull the cage liner away from the backup structure, indicating that the pre-load in the liner is satisfactory. However, some tooth-marks were left in the liner coating.

Test highlights are presented as follows:

- The primate did not injure himself on any of the test hardware.
- The preload between the cage liner and the backup structure was satisfactory and will resist primate attempts to pull the liner inward.
- The social window bars will retain the primate and will not deflect enough to permit his exit from the cage.
- The primate seems to adjust well to the cage configuration.
- Behavioral task panel levers can withstand primate abuse.

After completion of this first phase of the primate/equipment interface test, the TFDM hardware was moved from the manufacturing facility in Sunnyvale to the acceptance test facility area at the Biotechnology Laboratories in Palo Alto.

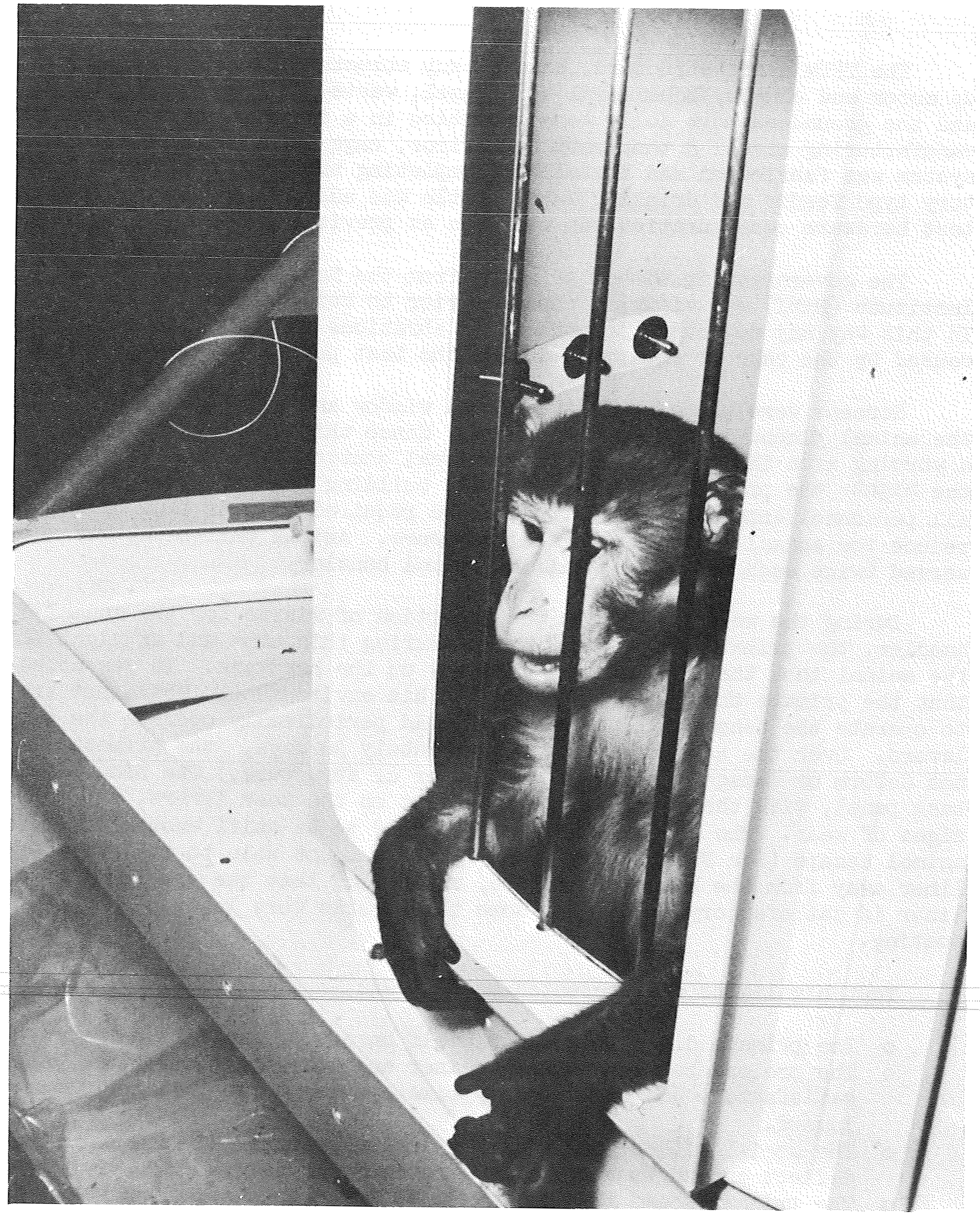


Figure 45 Primate/Cage Interface Test

The remaining subsystems, as they were completed, were added to the TFDM. The ground control console with the interconnecting wiring was placed in the adjacent room and the completed systems checked out. The waste management system was installed on the TFDM and standard laboratory feeding and watering equipment clamped to the social window bars. The complete louvered floor assembly was installed during this period. The primate was inserted through the side TV camera port and the side TV camera mount installed.

The primate was removed after approximately 48 hours to facilitate the installation and checkout of other systems. No adverse results to primate or equipment were noted.

Prior to re-inserting the primate, the end item feeder and waterer were installed and checked out. The feeder was loaded with 3480 grams of food tablets and the drinking water system charged. The goal for this phase of the interface test was to observe how the primate would adapt to the feeder and water lip devices and to train the primate to receive food tablets and water aliquots from these lip devices. The primate was inserted through the side TV viewing window.

A remote control override switch was patched into the feeder control system so that tablets could be dispensed by an operator upon his command. The remote control device was used to arm the feeder only when the primate's mouth was on the lip device, limiting food reward to oral responses. After a few unsuccessful attempts using his hands to actuate the lip switch, the primate started using the oral technique essentially 100% of the time. The water system was then energized and water dispensed several times from the control console. The primate put his mouth on the lip device and the system dispensed another aliquot. Some of the water went into the primate's mouth and some on his face. After several dispensing cycles, the animal learned to operate the lip switch correctly. The water aliquots were set to dispense 4 cc during this test. It was noted that the primate would not always drink all the water dispensed but would let some spill from his mouth. The water aliquot was reduced to 3 cc prior to the final acceptance test with successful results.

The primate acceptance of both the food tablet lip device and the water lip device was satisfactory. The primate learned how to operate both devices without error within one afternoon. The cue lights on both devices worked properly and the level of the cue light was sufficient to attract the primate's attention.

Following the feeder/waterer interface test, the retrieval system including floor displacement, louver closure, cage liner retraction, and retrieval piston actuation was checked and readied for testing with the primate.

This test series was to demonstrate the existence of any potential hazards to the primate during the recovery sequence or the ability of the primate to damage the hardware systems during recovery, resulting in failure to meet design requirements.

An observer was stationed at the social window during this series of tests to observe primate safety status. On command, the floor was translated to the "up" position by the pneumatic actuators. The response from the primate was almost as fast as the translation of the floor. The primate, upon sensing the movement of the floor beneath him, jumped to the top of the cage assembly, and bridged his body across the diameter of the cage. While the primate was in this position, the floor louvers closed on command. In a minute or so, the primate returned to the floor.

Cage liner retraction was commanded and the liner began its roll-up sequence with a clean separation from the back-up structure. Visual attention was given the liner position during rollup relative to the lip devices and behavioral task panel levers. The liner travel past these protuberances was the same as observed during development testing of this system. The primate did not seem upset by the liner retraction and did not offer resistance to the rollup process. The primate followed the liner wall as the diameter of cage decreased, and until the liner seated on the 14.0 inch diameter ring at the retrieval piston. At this point, the primate was within a 14" diameter by 48" long cylinder directly on top of the retrieval piston and lined up with the retrieval canister. The pneumatic retrieval piston was actuated from the control console. The piston slowly raised the primate into the retrieval canister. Lockup of the piston floor into the bottom of the retrieval canister was not accomplished during this test due to misalignment problems. This final operation was observed through a plexiglas cover on top of the retrieval canister. The process was then reversed without incident and the liner seated correctly against the cage backup structure.

Results of the retrieval test were satisfactory except for lockup of the canister floor. The other mechanical systems involved all functioned as designed. Primate response to the retrieval operation was excellent; he did not resist any part of the operation. It was also demonstrated that the retrieval system would not physically injure the primate during the retraction or extension of the cage liner, and the extension and retraction of the retrieval piston actuator.

The noxious stimulus system was also operated during this series of tests. This system can be operated automatically through the behavioral programmer or through manual command at the control console. The purpose of this system is to provide a noxious stimulus to the primate from which he can escape by retreating to the retrieval canister. Here his presence is sensed and the noxious stimulus terminated.

The system was energized and the primate first jumped off the floor but then walked around the floor trying to avoid the gas jets. He did not go into the retrieval canister.

The water system was shut down during this period as an electrical malfunction was found in the feeder/water system. When the primate operated the feeder, the water system was also energized. To prevent de-training on the feeder, a standard laboratory waterer was installed on the social window bars, while correct action was completed on the electrical malfunction.

After several days, the noxious stimulus system was again tried. This time using only the noxious stimulus jets in the floor. Again, the primate did not go into the retrieval canister. He was able to find a location within the cage area where the air blast did not reach him. A more detailed study of this problem resulted in the relocation of the four existing jets and the addition of seven others. The jet openings were increased from .030" to .040".

The retrieval system was operated but with the retrieval canister removed and a net placed over the opening. The primate was successfully placed into the net via the retrieval piston without incident. With the primate removed, the complete TFDM was checked and no damage of the floor or interior of the cage assembly could be found.

The primate/equipment interface test was interrupted for several days to allow for the behavioral programmer demonstration. Upon completion of that demonstration, the primate was again placed in the cage assembly to complete the primate/equipment interface test. The main problem still remaining was the fact that the primate was not responding properly to the noxious stimulus.

After the primate had adjusted to being in the cage again, the noxious stimulus system was energized from the control console and the 11 jets placed in operation. This stimulated the primate more than the 4 jets, but it still did not cause him to enter the retrieval canister. A second run was made, this time actuating the floor translation system first, then the noxious stimulus jets. This caused the primate to go to the top of the cage and bridge across its top diameter with his body, but he did not go into the canister. The system was shut down and when the animal came down from the top of the cage, he was rewarded. This was followed by actuating the system in the AVD automatic mode through the behavioral programmer. The 10KC tone sounded, the animal did not move, consequently, the air jets were operated. The animal jumped to the top of the cage, the jets were disabled, and the animal rewarded. This procedure was repeated several times and the primate responded in a similar manner and was rewarded each time. During some of these tests, the 2000 cfm purge fan was energized when the animal was at the top of the cage, the goal being to encourage the primate to seek sanctuary in the retrieval canister. While the primate did not like the high velocity air, he found some relief by hanging on the exerciser. The exerciser was then fully retracted and the operation repeated. Primate response was to bridge the top of the cage in an area where he was least effected by the high velocity air, still not entering the retrieval canister where he could escape the air blast in total.

The exerciser was in the cage system during all primate equipment interface testing. The primate at this time did not know how to operate the device but used it many times for climbing purposes. It received considerable abuse, but was not damaged in any way. Its operation was satisfactory prior to primate exposure and was unchanged at the end of the test series. The last system under the primate/equipment interface test to be checked was the primate vocalization monitor. This system consists of a microphone located in the cage ceiling which receives the primate vocalizations. These sounds are broadcast to the control console mounted loudspeaker and also operate a voice operate relay (VOR) which, in turn, starts a tape recorder. A 3.5 second time delay relay shuts off the recorder. The goal of this system was to record all animal vocalizations during a test period.

The system was energized and primate sounds simulated. The system operated and the sounds were recorded. The ECS fans, both 200 cfm and 12 cfm were energized. The resulting noise operated the voice operated relay and the sounds were taped. The electronic circuit was then adjusted to operate at a noise level above the ambient fan noise. The system was again checked and now operated only when a noise greater than that of the background was emitted. For the primate to operate the system, however, he must emit a noise greater than that of the background. The NAMI primate 2Z4 was not by nature very vocal. Only on rare occasions did the primate actually trip the VOR and make a recording.

Several other problems with this system became apparent during this testing period. The audio clicks of the vigilance task caused the VOR to operate. In addition, the 5 KHz tone, a part of the timing regimen, would energize the system as would random fan noise spikes.

While working with this system, in an effort to improve performance prior to start of acceptance test, it was also found that if the primate would emit just one loud sound, that sound would not get on the tape. If he emitted two sounds close together, the second would be recorded but not the first.

This was caused by the fact that while the tape recorder was on full time, the tape transport motor was not running. When the sound signal was received at the VOR, it would turn on the tape transport motor. However, it required 2.5 to 3.0 seconds for the motor and the tape drive system to get up to recording speed. Consequently, the first sound emitted by the primate was over before the recorder was in a condition to record it. The solution to the problem would be a major modification to the tape recorder. The decision was made to improve the system as much as possible by adjustment, and defer major modifications to a future time.

To summarize the primate/equipment interface test series, all major systems, i.e., feeder, waterer, waste management, exerciser, behavioral panels, ECS fan system, and retrieval system worked well and the primate was able to operate or be controlled by the systems as designed. No primate damage was detected on any of the equipment exposed to the primate.

Two systems did not perform as desired. The noxious stimulus system was a partial success in that the system was indeed noxious to the primate, but it did not evoke the desired response. The noxious stimulus system problem was solved during the acceptance test.

The sound detection system did work, but not within the desired sound envelope. Solution to this problem requires a major modification to the tape recorder, relocation of the microphone within the cage, and reduction in fan noise.

Mass measurement system test.- The mass measurement test was originally planned to be accomplished during the development test phase of the program. However, due to lead time required for the purchase of the load cell system, and the fact that the TFDM basic structure and floor assembly were required to perform the test series, it was re-scheduled to be accomplished during systems testing.

The mass measurement system for the TFDM utilizes three conventional load cells which support the entire cage floor system, including the retrieval piston and actuator. The tare weight is electronically zeroed. Digital visual readout is provided with adjustment controls on the console as was shown in Figure 16. An analog output is provided for recording.

The accuracy for the mass measurement of a 13 to 15 pound primate for this type of system was estimated at 1% of actual primate mass.

A set of calibrated weights from the LMSC Standards Laboratory was used for all testing. The system was calibrated and weights totalling 13 pounds were placed on the cage floor. Typical results are shown in Table 2.

Table 2
Mass Measurement Test Results (Initial)

Floor Test Point	Actual Weight Pounds	MMS Readings in Pounds
1	13.0	13.17, 13.17, 13.21
2	13.0	13.32, 13.07, 12.97
3	13.0	11.82, 11.76, 11.64
4	13.0	12.43, 12.37, 12.47
5	13.0	12.40, 12.39, 12.43

The floor translation system was cycled and readings taken again. Readings were also taken with the floor in an "Up" position with the louvers open. As can be seen by the results, as the test weight was moved to various floor positions, the readings were not repeatable, with spreads up to 1.68 pounds. This performance was not acceptable.

A careful study was made on both the electronic system and the installation of the load cells in the TFDM. The load cells were removed from the TFDM, bench-checked, and found to be satisfactory. It appeared that the floor, which is supposed to float on the load cells, was at times rubbing the TFDM structure. Mass measurement system performance was ultimately corrected during the acceptance test.

Feeder vibration test.- After completion of the tablet vibration test previously described, a detailed study by the LMSC Flight Dynamics group was made to determine the vibration levels that the feeder would actually experience, mounted in the payload section of the OPE spacecraft which, in turn, is mounted in the LM adapter section on a Saturn S-1B vehicle. As the detail design of the feeder progressed, configuration information was transmitted to the dynamics group to be used in the analysis of the flight dynamic profile.

This study reviewed the principal random vibration environment present during the periods of flight when the acoustic excitation is most severe, that is during lift off, periods of transonic mach numbers and high aerodynamic pressure. The random vibration transmitted mechanically from the various engines to the OPE spacecraft will be much less severe than acoustically-induced vibration and therefore did not influence the random vibration spectrum as shown in Figure 46. During flight, random vibration exists for periods of 7 seconds at lift-off, and 40 seconds at periods of transonic mach numbers and high aerodynamic pressure.

The feeder will not be exposed to any pure sinusoidal excitations during flight, only rapidly decaying complex transient vibrations associated with ignition and shutdown of the various booster stage engines. However, the sinusoidal sweep test is valuable for detecting design deficiencies and the frequencies at which failure is most likely to occur. The recommended vibration test levels at the feeder mounts were as follows:

Sinusoidal levels - Sweep from 5 to 400 Hz and back in approximately one (1) minute. Repeat in each of three mutually perpendicular axes.

5 - 7.5 Hz	1.0 inch double amplitude
7.5 - 400 Hz	3-g overall level

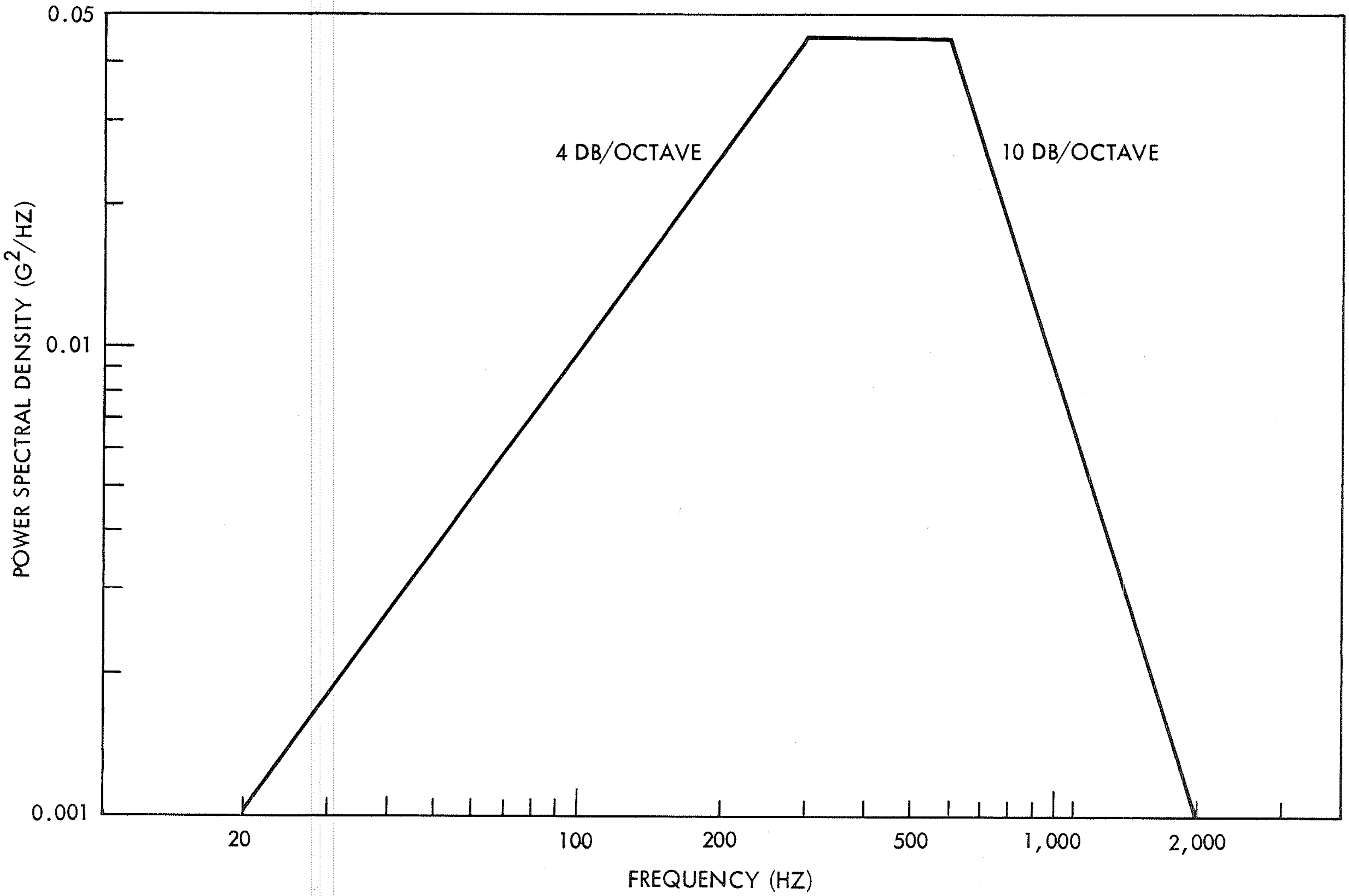


Figure 46 Random Vibration Test Spectrum

Random levels - One (1) minute in each of three mutually perpendicular axes.

20 - 300 Hz	4 db/octave rise to 0.045 g^2/Hz
300 - 600 Hz	0.045 g^2/Hz
500 - 2000 Hz	Roll off at 10 db/octave

The above vibration exposure levels were submitted to NASA-LRC for approval prior to testing. The review resulted in the sine sweep from one minute to two (2) minutes.

Prior to final assembly of the test feeder, three accelerometers were bonded to the feeder upper bearing plate as shown in Figure 47 and one accelerometer in the center of the feeder base plate as shown in Figure 48. One additional accelerometer was bonded to the negator spring bracket at the top of the feeder. With the accelerometers installed, the final assembly was completed.

The feeder was mounted in a ground handling fixture for system checkout, transport to the vibration test facility, and for feeder support during the accelerated life test. The feeder received a careful visual inspection and the electrical interface completed. The feeder was actuated manually to insure that all mechanical interfaces were operating properly.

With proper operation verified, the feeder was filled with 10 lb of food tablets from Drum No. 1, Lot No. P-6, Control No. 313810. The food tablets were processed by Stan Labs, Inc., Portland, Oregon. The feeder was cycled manually and it dispensed one tablet. The electrical system was then energized and tablets dispensed by lip device manual override and also by actuating the feeder lip device.

The feeder was then loaded with 85,000 food tablets based on the average weight of 10 tablets taken from four different drums. Of this shipment of test tablets, the average weight was 0.63 grams. A total of 118 pounds of tablets were loaded into the feeder meeting the 85,000 tablet requirement. The feeder was then topped off with 22.5 pounds of tablets filling the feeder to capacity (140.81 lb or approximately 101,155 tablets).

The feeder control system was energized and 100 food tablets were dispensed using the #1 drive motor and by manual actuation of the lip device, without incident. Motor #2 was then selected, and 10 tablets dispensed using the same technique. The lower dust cover was then installed and the above process repeated, dispensing three tablets using motor #1 and two tablets using motor #2.

The feeder, mounted in the ground handling fixture, was weighed upon arrival at test laboratory. It was then removed and placed in the vibration test fixture. The ground handling fixture was then re-weighed with the difference being the actual fully loaded feeder weight of 222 pounds.

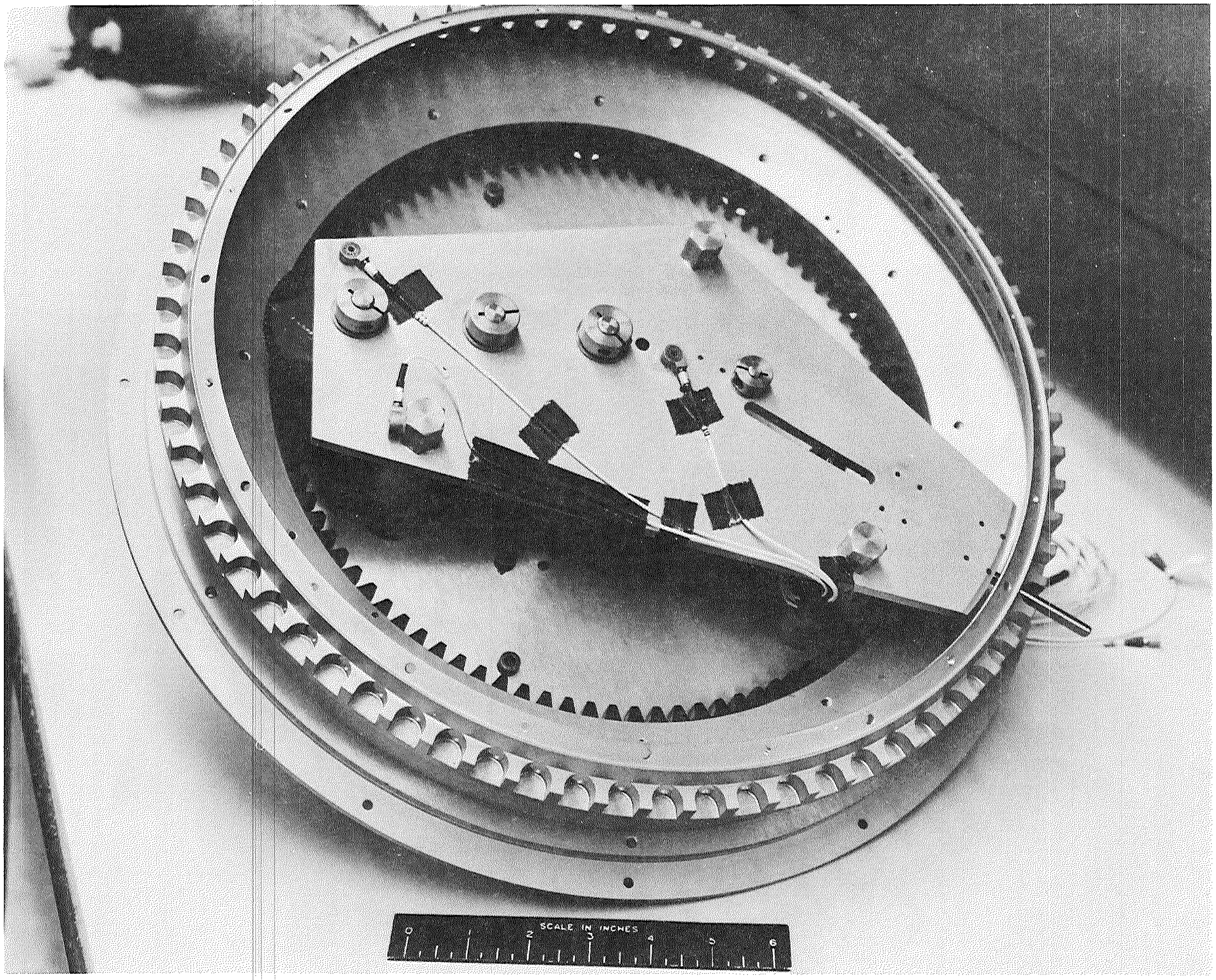


Figure 47 Accelerometers Mounted to Feeder Bearing Plate

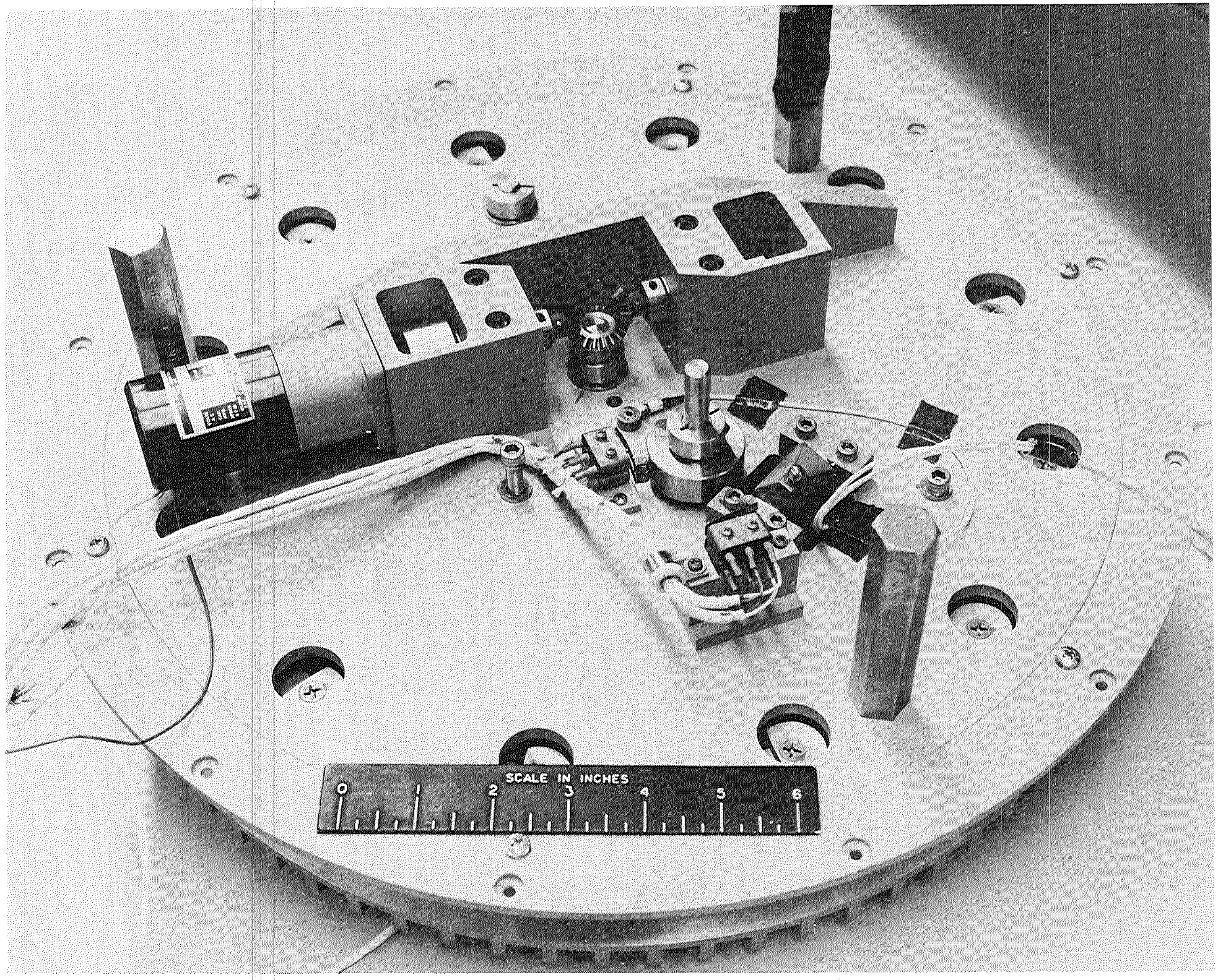


Figure 48 Accelerometers Mounted to Bottom Center of Feeder Base Plate

The vibration test fixture was fabricated of high damping magnesium in order to eliminate undesirable resonance characteristics. The vibration test fixture was bolted to a slip table which, in turn, was mounted to a Ling 7,500 force pound vibration system. The Ling shaker operates in conjunction with a sine sweep oscillator and a random noise generator. The shape of the random spectrum is controlled by an equalizer/analyzer network.

Three control accelerometers, one in each axis, X-X, Y-Y and Z-Z were mounted to the vibration test fixture. Figure 49 shows the accelerometer installation with the specimen in the Y-Y axis.

Both sine and random vibration exposure levels were run with the feeder in this orientation. The vibration test fixture and feeder assembly were then rotated through 90° and remounted to the slip table. This placed the specimen in the X-X axis for both sine and random vibration runs.

For the Z-Z orientation, the feeder assembly was rotated 90° about its axis, within the test fixture as shown in Figure 50. Both sine and random vibration levels were run in this configuration.

After vibration testing, the feeder was carefully inspected for any damage resulting from the vibration test. The aluminum plate over the feeder inspection port was removed in order to view the food tablet visable through the plexiglas window. Some tablet dust and unidentified foreign material was visible on the interior surface of the window. Tablets in the field of view showed no signs of damage. Some tablets showed exterior dust.

The feeder fill access door in the top dust cover was removed and a general inspection of the area revealed no damage. The second door in the tablet cone pressure plate was removed to allow access to the tablets for detail inspection. Several handfuls of tablets were removed. Tablet condition was excellent. No chips, broken, or split tablets were found. The tablets were replaced in the feeder and the access door re-installed.

The lower dust cover was removed and the drive motors, clutches, cam and other exposed mechanisms were checked for any damage. None was found. The lower dust cover was not replaced. This was to allow visual access to the mechanism during the operational check. The feeder was readied for operation per the test procedures and the lip device actuated by hand. The feeder dispensed the first tablet after the vibration test without incident. The tablet condition was studied and no abnormalities were found.

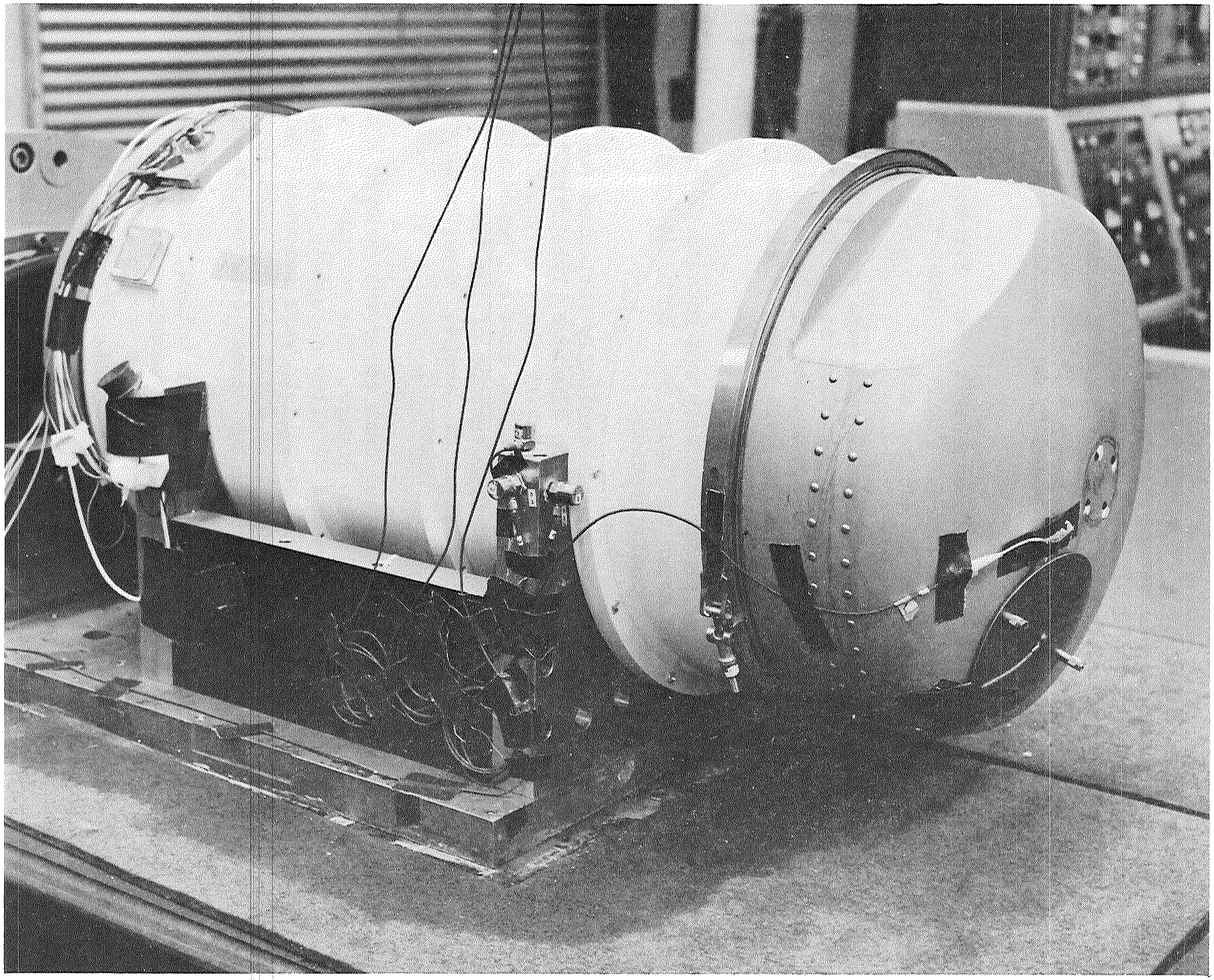


Figure 49 Control Accelerometers Installation

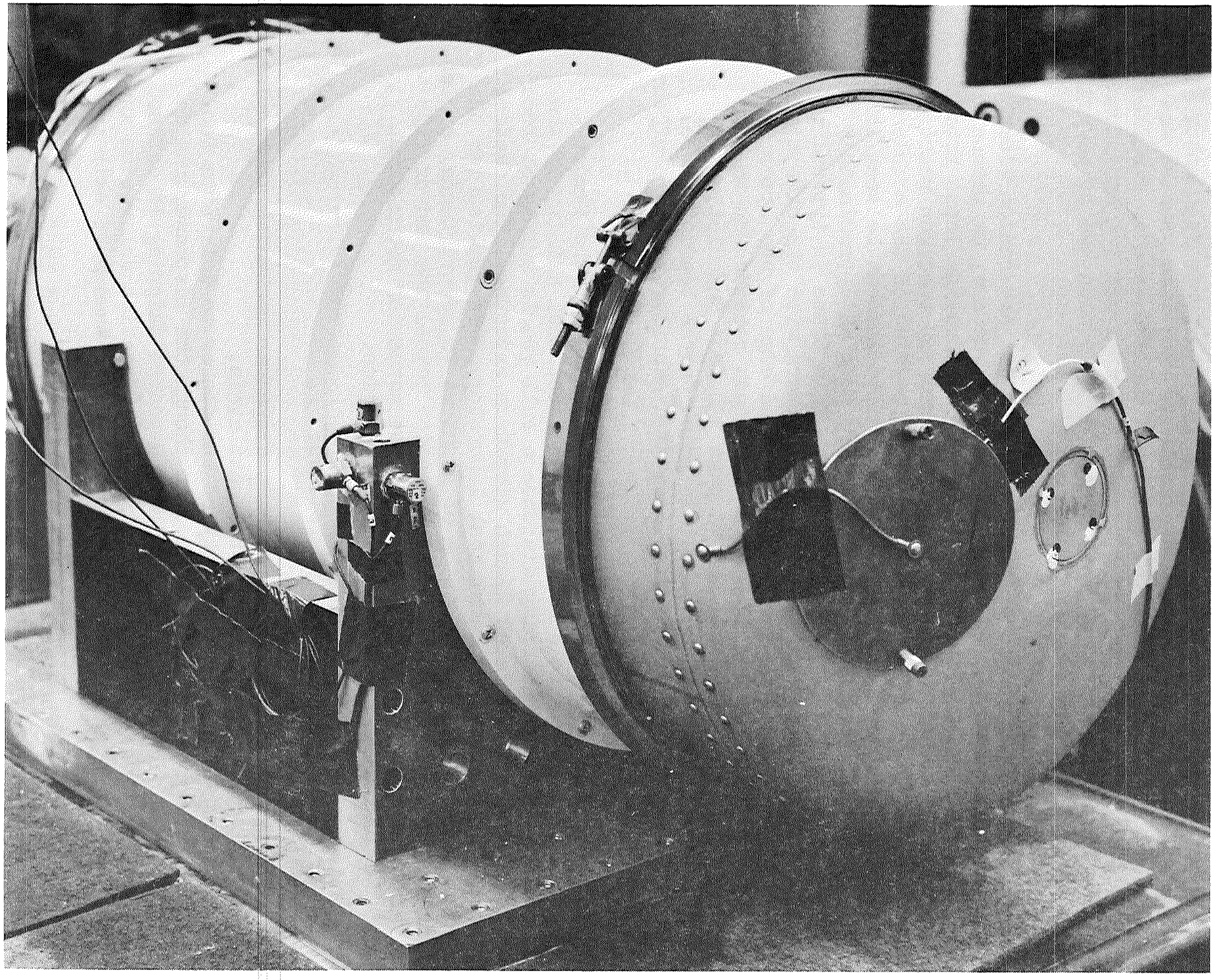


Figure 50 Feeder Installation in the Z-Z Axis

The feeder system was then cycled 50 times with power from motor #1 without a miss. Tablet condition was excellent. The same process was repeated on motor #2. Again, the 50 dispensed tablets were in excellent condition. The control was switched back to motor #1 and two additional tablets were dispensed to insure that the motor selection had no adverse effect on the feeder operation.

The feeder system withstood both the sinusoidal and random vibration tests without any damage to the tablets, feeder structure, or mechanism. The control accelerometers verified the required vibration input from the 7,500 force pound vibration system. The trace of specimen reaction accelerometer #10 is shown in Figure 51. The position of the accelerometer was in the center of the upper bearing plate and can be seen in Figure 47. The high readings of the trace are 30 g at approximately 160 Hz and 18.6 g at 280 Hz in the Y-Y axis. This trace is typical of the sinusoidal vibration seen by all accelerometers with the exception of #11, which was located on the upper left-hand edge of the upper bearing plate and can be seen in Figure 47. Loads recorded on this accelerometer are 45 g at 165 Hz and 40 g at 338 Hz. Calculations indicated loads of this magnitude at this point on the bearing plate were due to the fact that the subject area is a cantilevered edge of the bearing plate.

Feeder accelerated life testing.- The objective of the feeder accelerated life test was to demonstrate the functional ability of the feeder assembly to satisfactorily dispense a full year's supply of food tablets following the simulated launch vibration exposure. The feeder, upon return from the environmental test laboratory, was readied for the accelerated life test by the addition of counters to record feeder cycles, lip switch actuations, count of tablet ejection beyond the end of lip device, and rotational count of the lip device actuation motor which simulated the primate's actuation of the lip device.

A feeder failure was defined as follows:

1. Jamming - Inability of the tablet dispenser mechanism to complete a full cycle or proceed to the next cycle.
2. Skipping - Repeated inability of the feeder to deliver a food tablet beyond the lip device even though the dispenser ram is proceeding through a full cycle. Repeated skipping is defined as the missing of more than sixteen (16) tablet deliveries in a four hour period. This quantity is less than a 1% skip rate.

Any failure was to be evaluated jointly by NASA and LMSC and a future course of action determined.

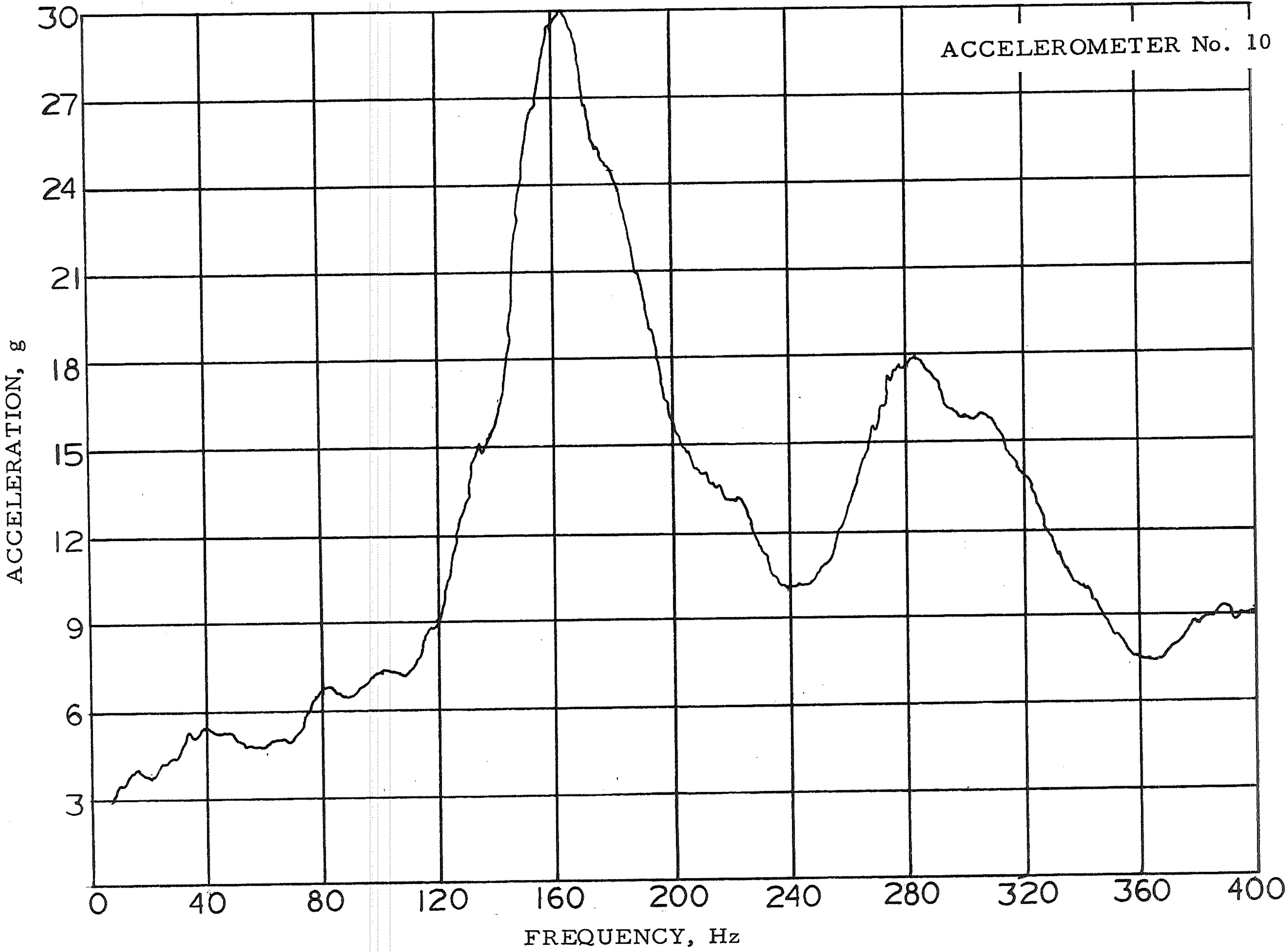


Figure 51 Typical Diagnostic Accelerometer Response Sinusoidal Vibration

Testing covered a time span of 30 working days, with the feeder in operation 8 hours per day. The system was shut down during the night hours. A detailed test log was maintained during the entire test period. The test setup can be seen in Figures 52 and 53.

Initially, test checkout was interrupted several times because of reliability problems with the simulated primate lip device actuator and the counter which recorded the tablets dispensed after leaving the end of the lip device.

After successful checkout of the feeder electronic control system, counting systems and the feeder itself, the official life test started at 1330 on 3-24-69. After one hour of operation, the feeder timing was in error. That is, the cycle would not be completed at the proper point on the cam mechanism. This was caused by excessive motor overrun, or coast, after the power was cut to the motor. This had not occured in earlier tests, but as the system wore in, friction was reduced and the overrun condition then developed.

Corrective action consisted of providing a DC current to the field coils of both drive motors to act as a dynamic brake when the 400 Hz power to the motor was cut. The cam timing was re-set and an operational check made, with satisfactory performance results.

Also, during this first hour of operation, the dispensed tablet counter proved unreliable. While the system was down for the incorporation of the dynamic brake, a new photo sensor counter was fabricated and tested. The device consisted of an aluminum tube about 24 inches long with a photo cell and light beam directed across the diameter of the tube. The tablet, after being dispensed from the lip device, rolled down the tube cutting the light beam and signalling the counter.

All counters were reset to zero, and the life test restarted at 0900 on 4-1-69. During the first hour of operation after the vibration test, the feeder dispensed 517 tablets without a miss.

The test continued until 1525 on 4-2-69, at which time it was noted that the lip device actuator was tripping the lip device, the drive motor was responding, but the feeder mechanism would not cycle. The mechanism was inspected and a failure of the bevel gear on the #1 drive motor was found. Inspection of the failed gear indicated that the subject gear was not a case-hardened gear. The drawing of the motor drive assembly was checked and it was found the engineering called for the correct gear. A further investigation revealed that the incorrect gear was ordered. This discrepancy was detected by the product assurance representative and brought to the attention of engineering. An assessment was made by engineering that the system would function successfully under the calculated loads using the soft gears, a decision which by test was proven wrong.

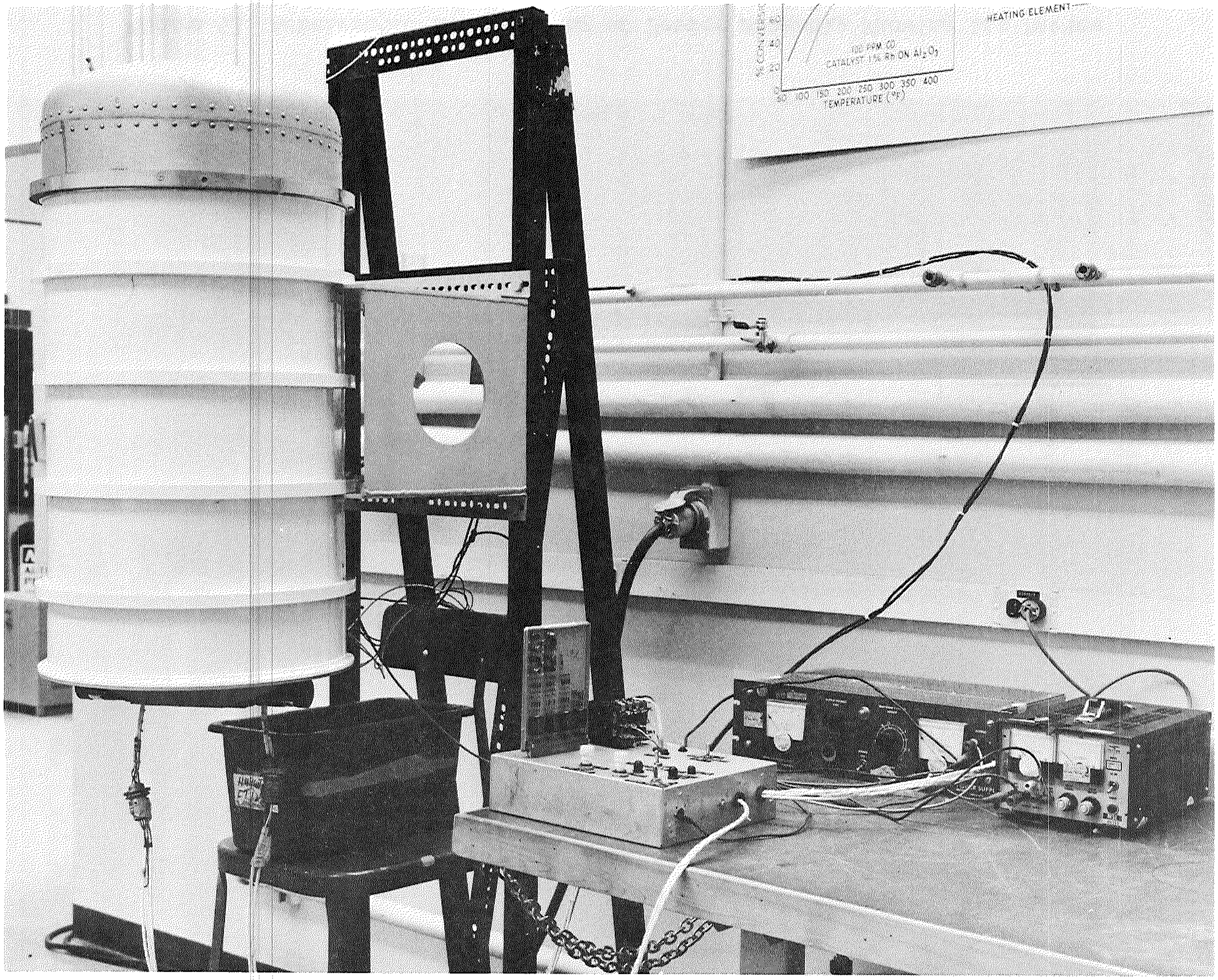


Figure 52 Accelerated Life Testing of Feeder Assembly Showing
Electronic Controls

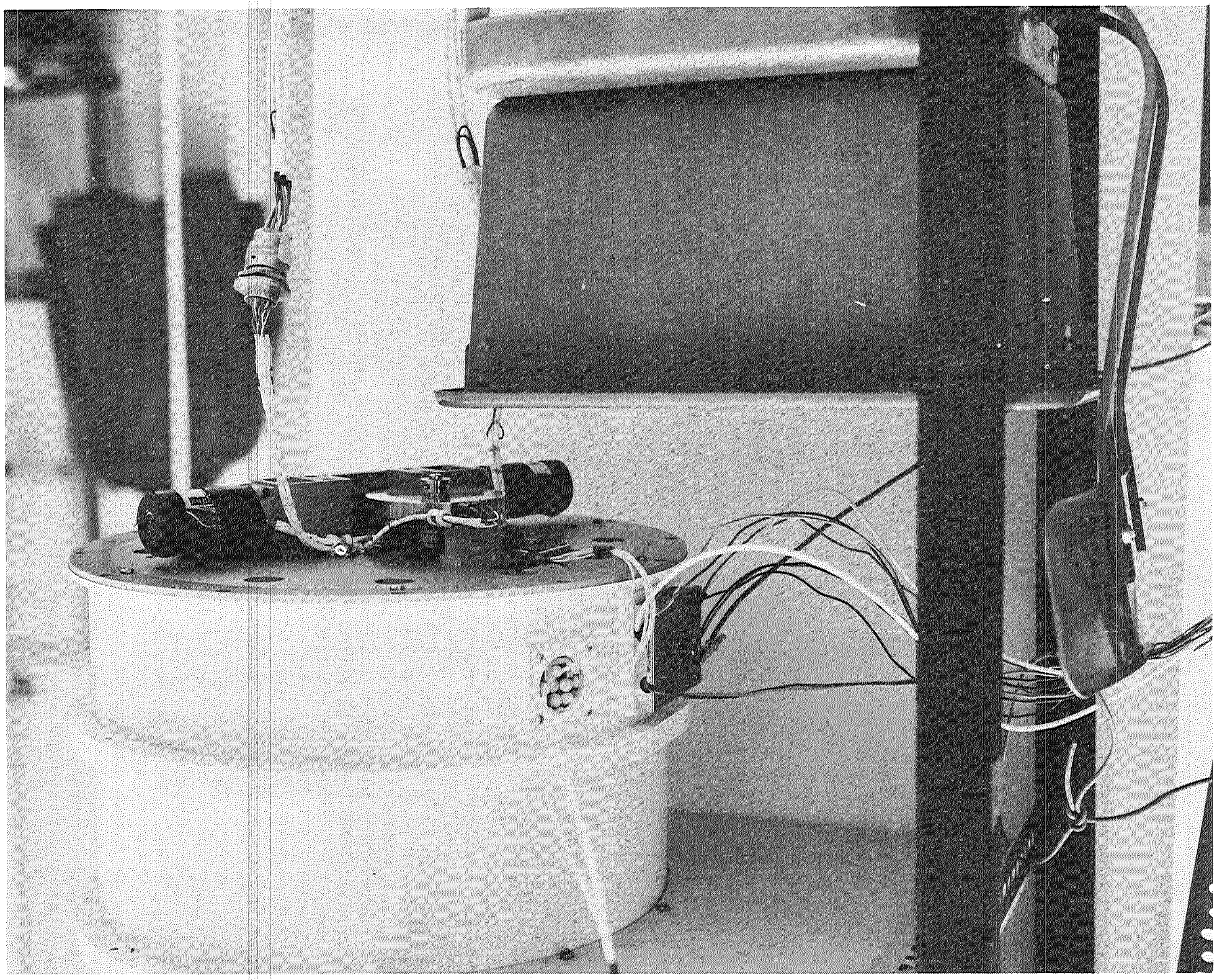


Figure 53 Accelerated Life Testing of Feeder Assembly Showing Lip Device

As a result of this failure, the complete bevel gear/pinion gear system was changed to case-hardened gears as the first release of the engineering had indicated. While the gears were being changed, a torque measurement was taken with the feeder full of tablets. Readings ranged from 30 inch pounds to 35 inch pounds. These values were in agreement with design and were not assumptions considered excessive.

Prior to feeder checkout and subsequent to the gear change, the gears were lubricated with a mixture of Shell SG-1012 per MIL-G-7118 and Molykote-Z per MIL-M-7866. A complete operational check was made and feeder performance was satisfactory. The NASA Program Office was notified of the failure and corrective actions. Agreement was reached that an additional 85,000 tablets would be dispensed from this point in the test. The test was restarted at 0930 on 4-7-69.

On 4-9-69, a half tablet was found in the dispensed tablet bin. A careful check every hour or so was made to investigate the broken tablet problem. On 4-14-69, the broken tablet problem was diagnosed and the test stopped.

The problem was related to the entrance port of the lip device. The existing 0.030" radius on the port entrance was too sharp. This can be seen in Figure 54. As the ram advances, it can catch a tablet between the flat of the ram and the entrance port of the lip device.

The fix was to enlarge the fillet radius on the inlet to the lip device. The lip device was removed from the feeder body and reworked as shown in Figure 55. The lip device was reinstalled on the feeder body and the complete system operationally checked. Operation returned to normal, the feeder started clearing itself of tablet crumbs, and no further damage to tablets was detected. NASA was consulted on the above rework and LMSC received approval for the rework and also permission to resume life testing without resetting the counters to zero.

Testing was resumed and was uneventful for about 16 hours, when the #1 drive motor started running free, with no torque being transmitted to the drive gear. An inspection revealed that the pinion shaft had been sheared. NASA was informed of the failure and LMSC received approval to disassemble the feeder to find the source of the problem.

The failure occurred while trying to index the receptacle plate, not during tablet ejection. The #2 motor was removed and an attempt made to rotate the face cam by hand without success, indicating that the jam was not caused by the second drive motor system.

The feeder was then disassembled part by part, each one checked as it was removed. The bottom mechanism was removed and all rubber strips were intact. The system at this stage could be rotated by hand through part of a ram operation and finally through a full cycle, but only by exerting excessive torque.

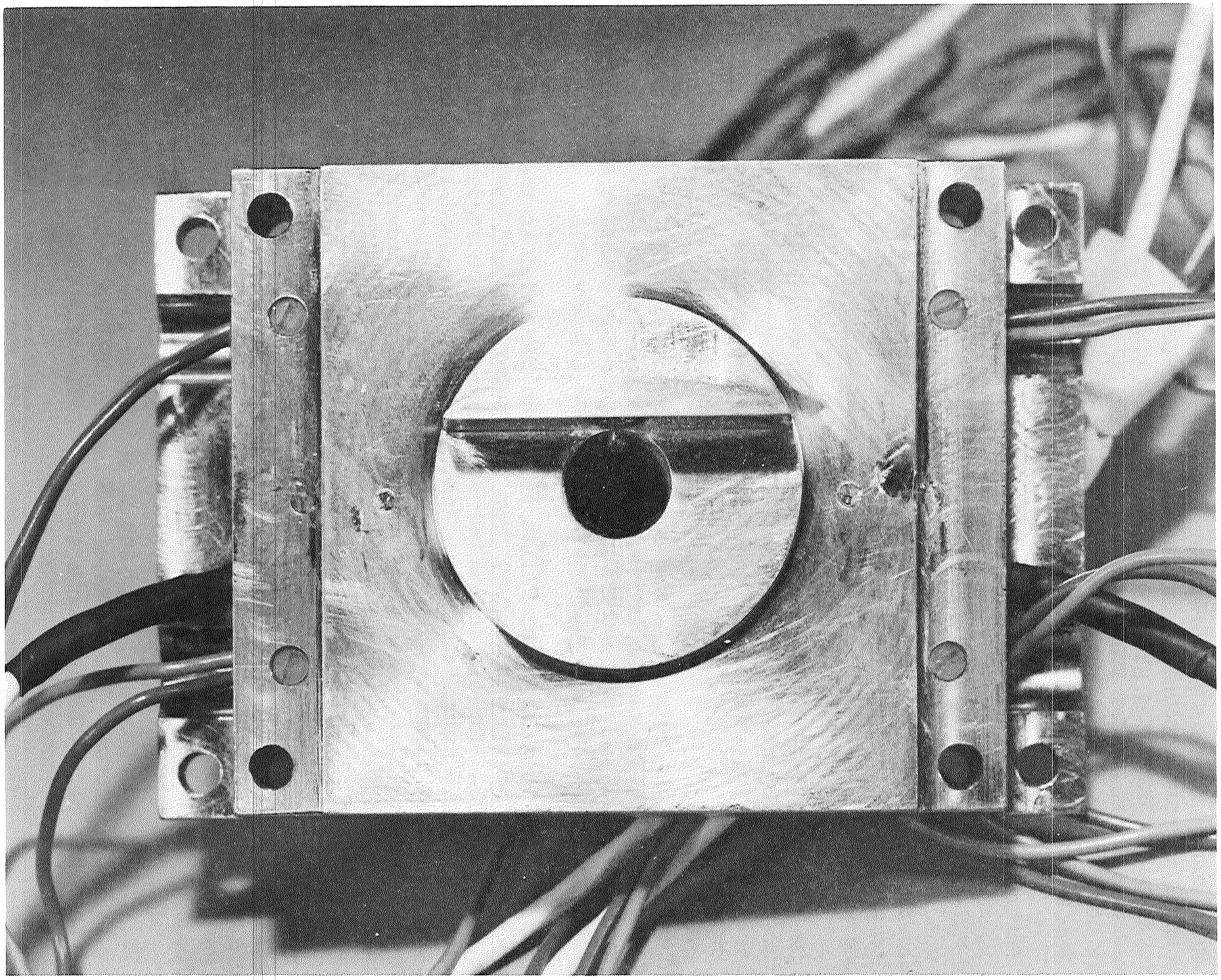


Figure 54 Lip Device Entrance Port Showing 0.030" Radius

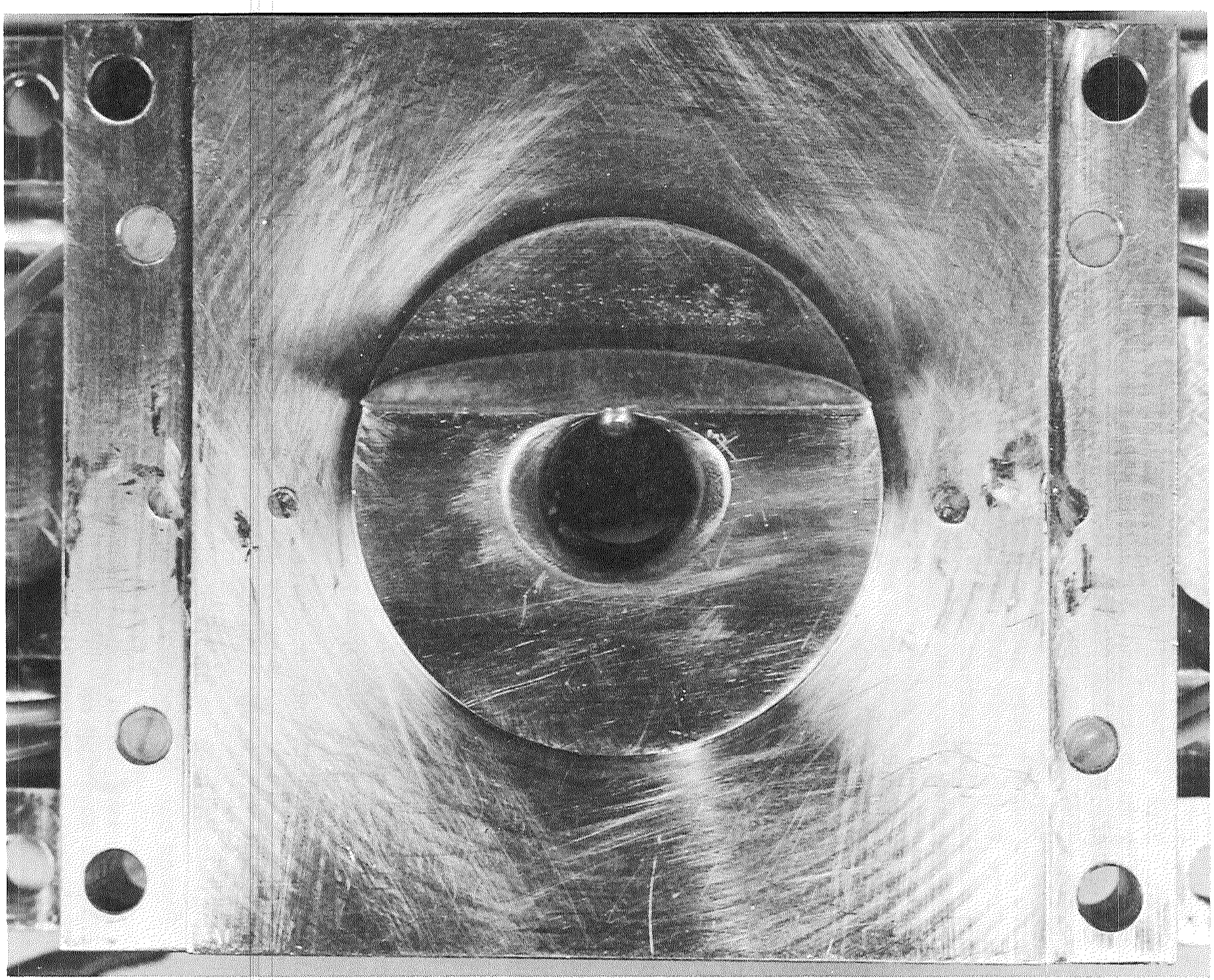


Figure 55 Lip Device Entrance Port Showing Rework

In order to find the source of the high torque, the upper bearing plate was removed. Some tablet dust was found in the ram bearings, but this was not causing any major problem. With the complete drive train apart, the tablet receptacle plate was rotated and found to be the source of the high torque. The large bearing upon which the receptacle plate rotates was difficult to turn. The bearing was dry, but did not have tablet dust in it. Three set screws were used to hold the outer race of the bearing in place. Where these screws were located, the bearing balls were found to be tight. Backing the screws out did not relieve the problem. The bearing was removed and the epoxy used to set the bearing was also removed. With the bearing removed, from the feeder, it ran free. When the bearing was re-installed in the feeder, it also ran free. Apparently the set screws caused elastic deformation of the outer race, the epoxy adhesive flowed into the gap, set up and maintained the deformation.

Bearing testing indicated that any galling which took place was not sufficient to interfere with the satisfactory operation of the bearing and the decision was made to reinstall the original bearing in the feeder. The bearing was lightly coated with Molykote M-77. The set screws were not installed. The bearing was held in place by lightly staking the surrounding aluminum bearing housing.

A new drive shaft was installed and the feeder completely reassembled. The feeder was then filled with tablets, and checked with successful tablet ejection. The feeder had delivered 25,624 tablets prior to the shaft failure and the test was restarted at this number with NASA approval.

The life test from this point on was uneventful. The feeder dispensed from 25,624 tablets to 85,000 without incident. Feeder operation was continued to tablet depletion and a total of 91,595 tablets were dispensed. A total of 65,971 tablets were dispensed from the time of the bearing fix to depletion, with no mechanical problems or known misses.

While failures did occur during the life test, none were attributed to the vibration exposure. A summary of the failures are shown below with the known cause and corrective action.

Failure	Cause	Corrective Action
1. Feeder out of time	Motor overrun	DC current motor-field brake.
2. Drive gear/pinion	Soft gears	Installed hardened gears.
3. Tablet shearing at lip device	Radius too small at lip device entry port	Enlarged fillet radius at lip device entry port.
4. Pinion shaft sheared	Incorrect bearing installation.	Lubricated and re-installed bearing by staking in place.

Some electrical problems with the control circuits became apparent during the test, but were solved and corrected, and did not have any affect on the mechanical reliability of the feeder.

All testing, rework, and changes effected on the feeder were done under Product Assurance surveillance, and all rework on the test feeder was also accomplished on the second feeder. The second feeder was installed on the TFDM and fully checked prior to acceptance test. No operational problems were encountered. After the accelerated life test, the number one feeder was cleaned and operational checked and found satisfactory. It was then packaged for shipment as a complete spare feeding system.

Water system accelerated life test.- The purpose of this test was to demonstrate and verify (1) the functional ability of the watering system to satisfactorily store and dispense a full year's supply of water in pre-determined metered increments, (2) the redundant capabilities of the water system, and (3) the water delivery velocity.

The water system was set up as shown in Figures 56, 57, and 58, complete with tankage to supply water under pressure, valve and metering (aliquot) accumulator assemblies, water filter, and a water lip device.

Test operations consisted of electrical setup of the system in a ready state, actuation of the water lip device by means of a motor-operated cam and discharge of the water into a graduate. The number of lip switch actuations was measured by a counter operated by the same cam used to actuate the lip device. The supply of water to be dispensed consisted of approximately 46.4 gallons of filtered tap water.

During setup and checkout of the system, the following discrepancies were discovered (despite reported successful supplier acceptance tests) and the noted corrective actions taken.

1. Upon filling the two water reservoirs and pressurizing them to 50 psig, leaks were noted at the flanges of each reservoir. The flange bolts were tightened but this did not eliminate the leak. After discussions with the supplier, the tanks were returned for re-machining of the flanges to achieve more squeeze on the "O"ring seal. This required several weeks of effort by the supplier, and NASA permission was obtained to proceed using a laboratory water storage vessel in order to test the remainder of the system.

2. Several valves and one aliquot accumulator were found to leak. These were returned to the supplier for corrective action and available spare units installed in the system.

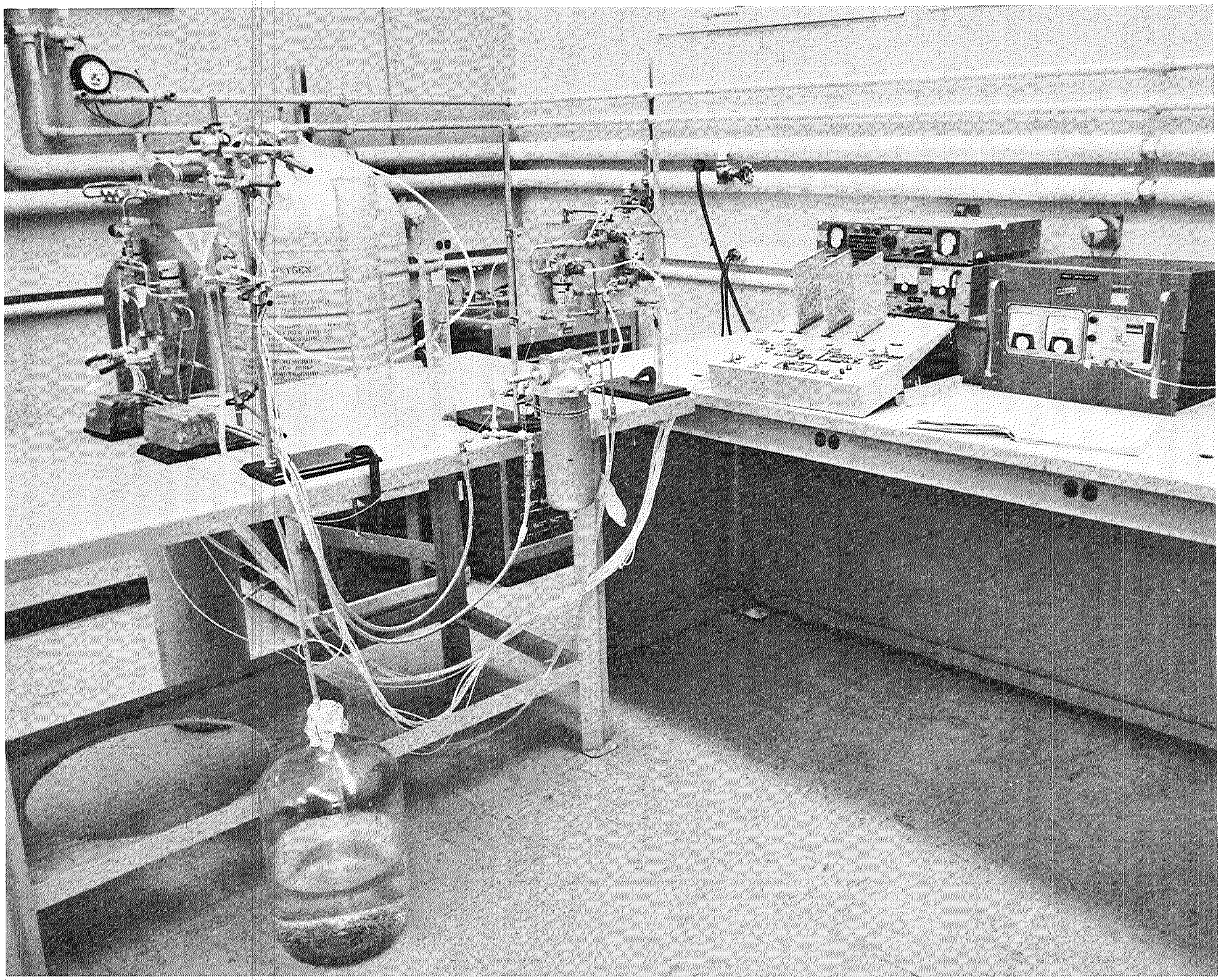


Figure 56 Accelerated Life Testing of Water System

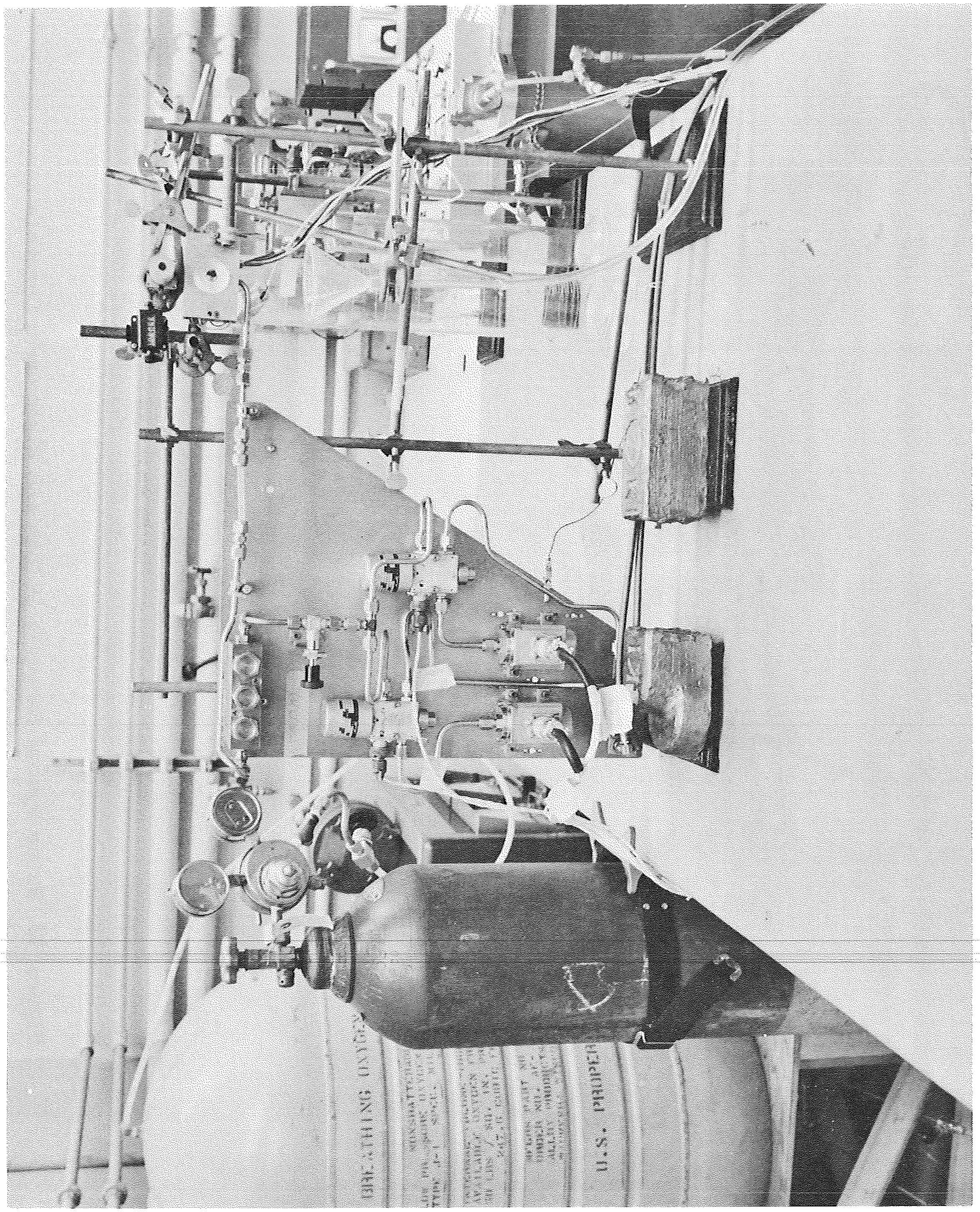


Figure 57 Water System Valve and Metering Panel

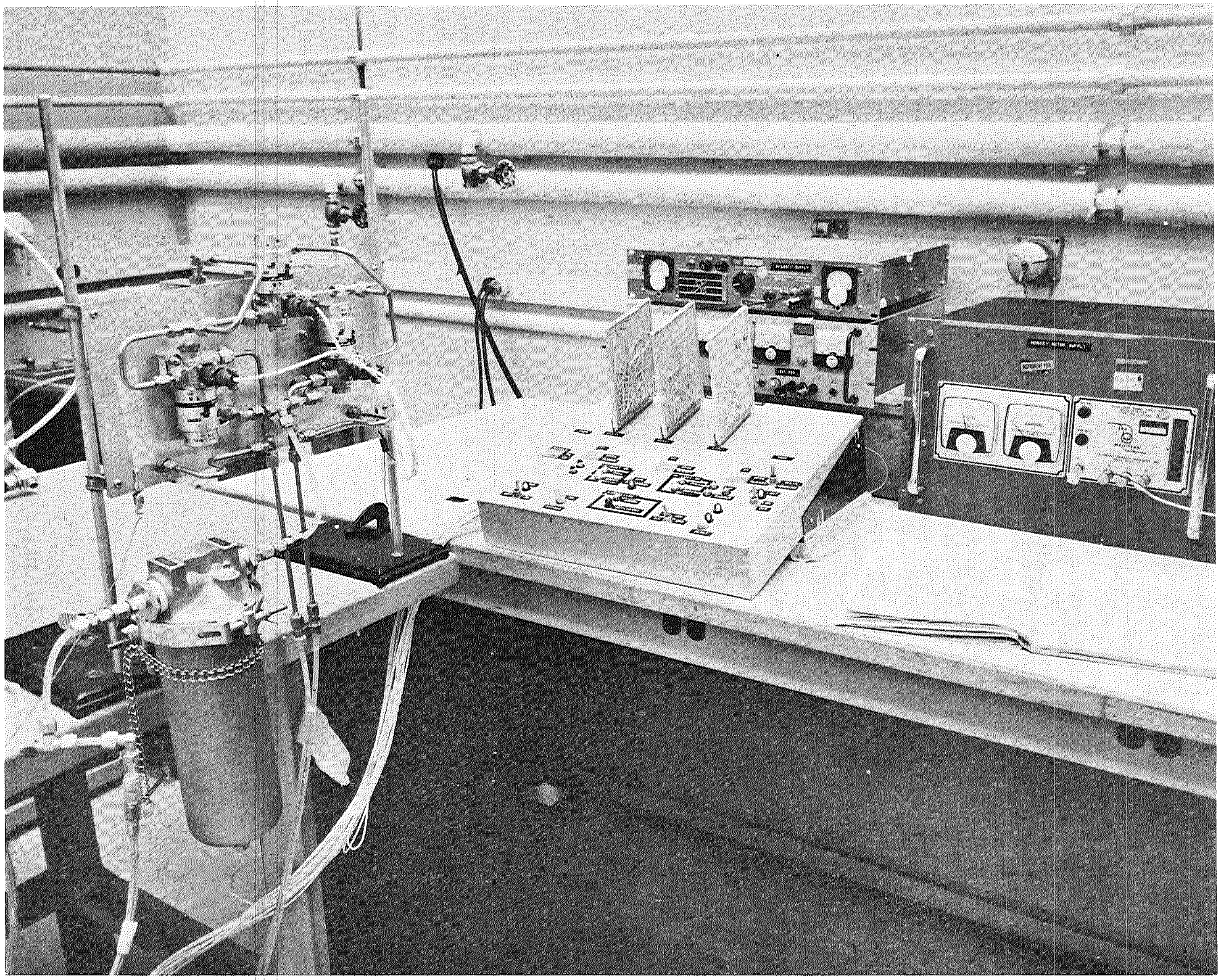


Figure 58 Water System Bacteria Filter and Electronic Controls

3. As water was dispensed from the lip device, part of it would run along the lower edge of the device and back into the housing containing the electrical switches and lights. This was corrected by inverting the device.

4. A brazed joint in the lip device failed due to lack of strain relief. This joint was rebrazed and the tubing properly supported to eliminate a repeat of the problem.

5. The lip device lever shape was modified to provide a more positive actuation of the lip switches.

6. Due to air trapped in the microbial filter (located between the aliquot accumulator and the lip device), water dripped from the end of the lip device after the accumulator discharges. This was due to the slow bleeding of pressure in the air pocket after an aliquot actuation. Several corrective actions were attempted, but all were unsuccessful. After discussions with the NASA Program Manager, a decision was reached to place the microbial filter upstream of the aliquot accumulators rather than downstream. This solved the problem, since pressure transients on the fill side of the accumulator had no effect on its discharge characteristic. In this way, a positive (non-dripping) discharge was achieved.

Following the above corrective actions, the system was determined to be ready for test. An initial check was made of delivery velocity by measuring the water discharge trajectory. Maximum discharge velocity (throttling valve fully open) was found to be approximately 22 cm/sec. The system was throttled to the desired delivery velocity of 15 cm/sec. The system was then actuated 50 times and delivered a total of 146 cc of water. The system had been set up to deliver 3 cc/actuation ($\pm$ 10%) and therefore, was operating within the specified tolerance. The test was continued, with the following daily results:

Test Day	Cumulative Actuations	Cumulative Water Dispensed (cc)	Average Aliquot (cc)
1	10,070	29,160	2.89
2	30,030	90,188	3.00
3	47,470	143,143	3.02
4	59,010	177,723 (46.9 gal.)	3.01

During the above test, two problems were noted and corrected, as follows:

1. One of the "aliquot full" microswitches failed to close, which in turn would not allow the aliquot fill valve to close. The circuit logic required both the "aliquot full" microswitches to operate even though one switch was redundant. Due to the precise mechanical alignment required to ensure that both switches closed at the end of the fill stroke, it was determined that the control logic should be modified to require closure of only one switch. After this was done, no further problems were experienced.

2. One of the "aliquot empty" microswitches failed in the closed position. This resulted in a continuous signal to the discharge valve to close. Consequently, the accumulator would fill satisfactorily but about 0.5 sec after the lip switch was actuated, the discharge valve would close. (Under normal operation, this valve would close when the accumulator closed one of the "aliquot empty" microswitches). Premature valve closure resulted in delivery of a short aliquot. A decision was made to lengthen the time delay for closure of the discharge valve to one second, thereby allowing the accumulator to fully discharge regardless of the status of the "aliquot empty" microswitches. No further problems were encountered in this function.

Following the accelerated life test, the redundant aliquot accumulator, its associated valve and the water tank selector and cross-over valves were all successfully operated and 1000 lip switch actuations performed in the backup mode. 2,900 cc of water was dispensed - well within the specified 3 cc/actuation + 10%. The test was completed with a final check of discharge velocity. At this point, it was determined that the aliquot discharge was most positive (no tendency to form a final drop) with the throttling valve wide open. This resulted in a discharge velocity of approximately 22 cm/sec. Agreement was reached with NASA to operate the system in this configuration during any further testing.

The test was concluded with a successful leak check of both reworked water reservoirs at 50 psig, repair of the aliquot accumulator failed microswitches, and modifications of the control logic system to include the changes described above.

Illumination and TV demonstration.- The objective of the illumination and TV demonstration was to evaluate the performance of the illumination and television monitoring systems.

The cage illumination system consists of four (4) Duro-Test Vita-Lite 15W fluorescent bulbs. Each bulb is controlled by a separate switch on the face of control console. The system can be operated in the manual control mode, or the automatic control mode, through the behavioral programmer. The illumination controls can be seen in Figure 13, previously presented. Also included in the illumination lamp assembly are two night lights which can be turned on when the TV lights are off. This system can be manual or automatic, as desired. The lamp assembly is mounted in the cage roof flush with the ceiling line.

To meet program goals, the illumination system must develop 25 $\pm$ 10 ft. candles of light measured at the cage floor. The night illumination level was to be between 0.05 and 0.2 ft. candles measured at the cage floor.

A model 700 log linear photometer with an accuracy of $\pm$ 2% of maximum scale reading was placed on the floor of TFDM cage. All external light was blocked off from entering the cage area. All lights within the cage were off. Light meter readings taken under these conditions (no lights) ranged from 0.026 to 0.027 ft candles.

The next series of tests involved turning on the Duro-Test Vita-Lite 15W fluorescent bulbs in sequence 1 through 4, and taking light meter readings at the cage floor as each lamp was turned on. Table 3 below shows the results.

Table 3
Illumination Test (Sequential)

Lamp No.	Ft. Candles at Cage Floor
1	10
1 & 2	20
1, 2, & 3	31
1, 2, 3, & 4	40

All four lamps were energized for one (1) minute and the readings taken again in the reverse order. Results are shown in Table 4.

Table 4
Illumination Test (Reverse Order)

Lamp No.	Ft. Candles at Cage Floor
1, 2, 3, & 4	45
1, 2, & 3	35
1 & 2	23
1	11

As can be seen from these results, the illumination level can be controlled within the design goal of 25 $\pm$ 10 ft candles of light at the cage floor.

Measurements were made with the night lights on and with the light meter placed in the center of the cage floor. The results are shown in Table 5.

Table 5
Illumination Test (Night Lights)

Voltage Level	Night Lights	Readings in Ft. Candles (First)	(Second)
28 VDC	2	0.114	0.113
12 VDC	2	0.030	0.029

The goal for night illumination level was in the range of 0.05 to 0.2 ft candles. With the night lights at 28 VDC, the system meets the performance goal.

With the possibility that the exerciser cue lights may be on during the night cycle, a light level measurement was taken with the night lights on at 28 VDC, and the exerciser cue lights on at the 28 VDC power level. The resulting light measurement was 0.145 ft candles at the cage floor.

Following the illumination performance tests, the side TV demonstration was accomplished per the approved test procedure.

The side TV system is mounted to the side of the TFDM cage in a special mounting fixture which contains a Mylar film transport system. The Mylar drive is operated from the control console. If the primate smears the Mylar film, the film can be transported providing a clean section of Mylar. A wire mesh screen protects the Mylar.

The test TV camera was a Cohu series 2000, 525 line unit. The camera was fitted with an Angenieux 94° 5.9 mm f/1.8 fixed focus wide angle lens. A Cohu standard 525 line monitor was used to observe the camera image.

The objective of this demonstration was to obtain a wide angle view of the cage interior with prime interest on the primate while at the behavioral panel, water lip device, food lip device and social window. All controls were to be used to produce the best picture possible by varying cage light level and camera lens f stops, as well as the TV electronic controls.

A standard TV test pattern was fixed to the cage interior just above the behavioral panel levers for initial check, then removed prior to placing the primate in the cage. A standard black and white photograph was taken of the presentation on the TV monitor of the best picture possible under each of the cage lighting conditions. Table 6 lists the results and the best black and white photo of the test series is shown in Figure 59.

With the primate removed from the cage and the standard TV test pattern installed above the behavioral panel, the following test was conducted.

One lamp was turned on and the lens stop set on f/1.8. The wide angle lens would not resolve the TV test pattern with sufficient detail to determine line count or shades of gray. The pattern would have to be approximately 6 inches from lens for full resolution. Figure 60 is a photo of the results of this test.

A night light test conducted with the night lights at the 28 vdc level, and the lens stop at f/1.8 revealed that only dark and light areas within the cage could be determined. A faint outline of the social window was visible.

The final operational check on the side TV system was the Mylar drive system. Black identification dots were placed on the Mylar at one edge of the camera field of view. With the #1 lamp on and the camera lens set at f/1.8, the Mylar drive switch was energized on the control console and held in that position until the black dots passed from the field of view. The system performed as designed.

The performance of the TV system was good, except for screen interference. The field of view was covered as desired; the behavioral panel water and food lip devices, social window, a portion of the exerciser, and about half of the cage floor was visible. The screen which protects the Mylar from the primate became very prominant under certain lighting conditions and lens f stops. This is a result of the very short focal length of the wide angle lens. The best performance of the system with the screen installed is with one illumination light on. The picture would be better if all lights could be on, the lens stopped down and the screen removed, but under these conditions, the Mylar is subject to damage by the primate. The blue cage interior provides good contrast between the primate and the cage wall.

The night-light TV viewing proved that with the night lights operating at 28 vdc, the camera lens wide open at f/1.8, only dark and light surface areas can be seen, and it is possible to see the outline of the social window.

The performance of the Mylar film transport was satisfactory.

Table 6

Side TV Lens Adjustment Data

Lamp No.	Lens f Stop	Remarks
1	22	Picture poor.
	11	Picture poor.
	5.6	Picture poor.
	4	Picture fair.
	2.8	Picture good.
	1.8	Picture very good. Black and white photo taken.
1 & 2	22	Picture poor.
	8	Focus on screen detail.
	4	Screen detail dropping out.
	2.8	Screen detail at minimum, best picture. Black and white photo taken.
	1.8	Least screen detail, but cage detail drops out.
1, 2, & 3	22	Picture poor.
	11	Screen in focus.
	5.6	Focus on screen detail. Good interior detail.
	4	Less screen detail. Good interior detail. Black and white photo taken.
	2.8	Loss of cage detail.
1, 2, 3, & 4	22	Picture poor.
	11	Focus on screen detail.
	5.6	Focus on screen detail. Good cage detail.
	4	Loss of screen detail. Good cage detail. Black and white photo taken.
	2.8	Loss of screen and cage detail.

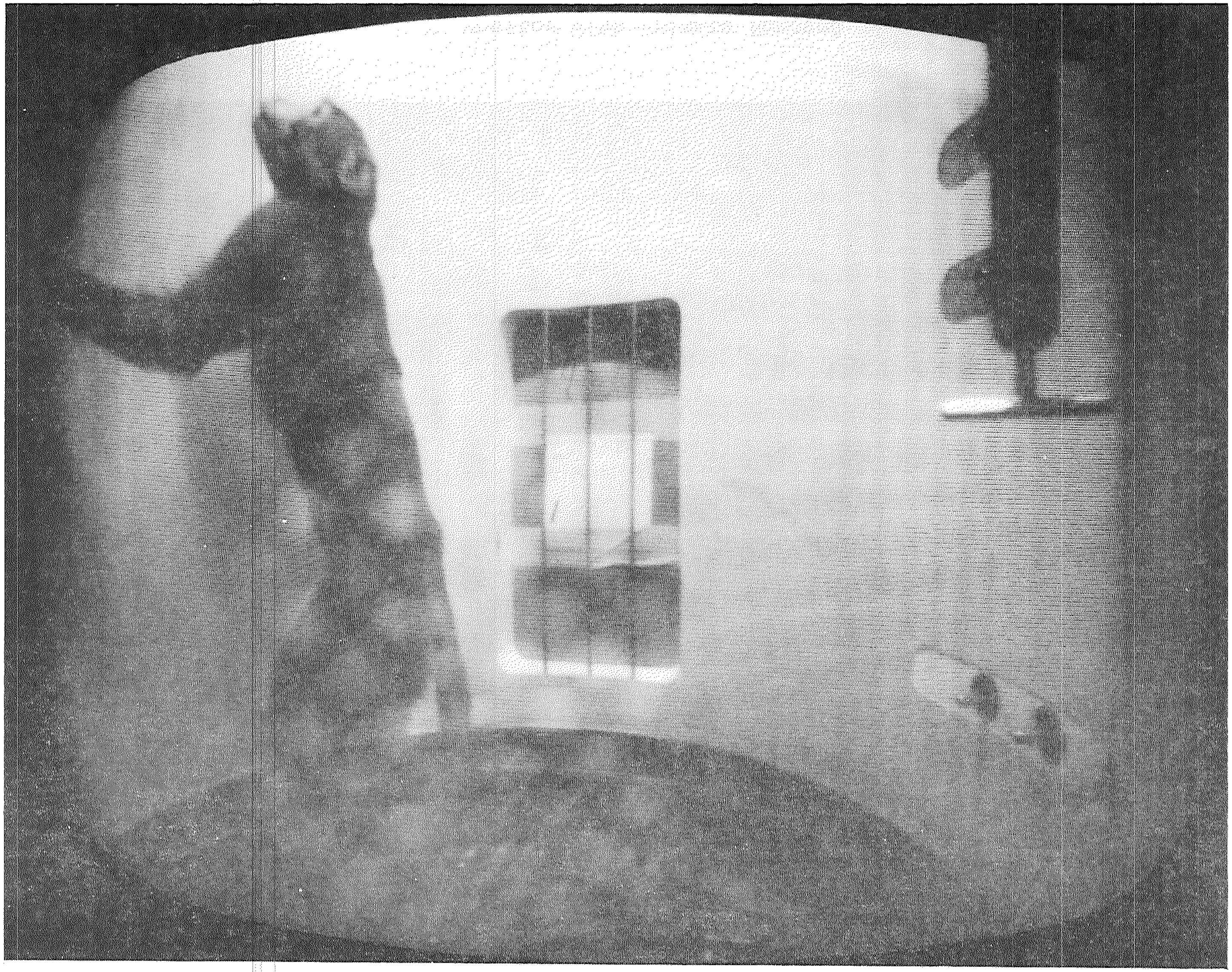


Figure 59 Photo of TV Monitor Showing Primate (Side Camera)

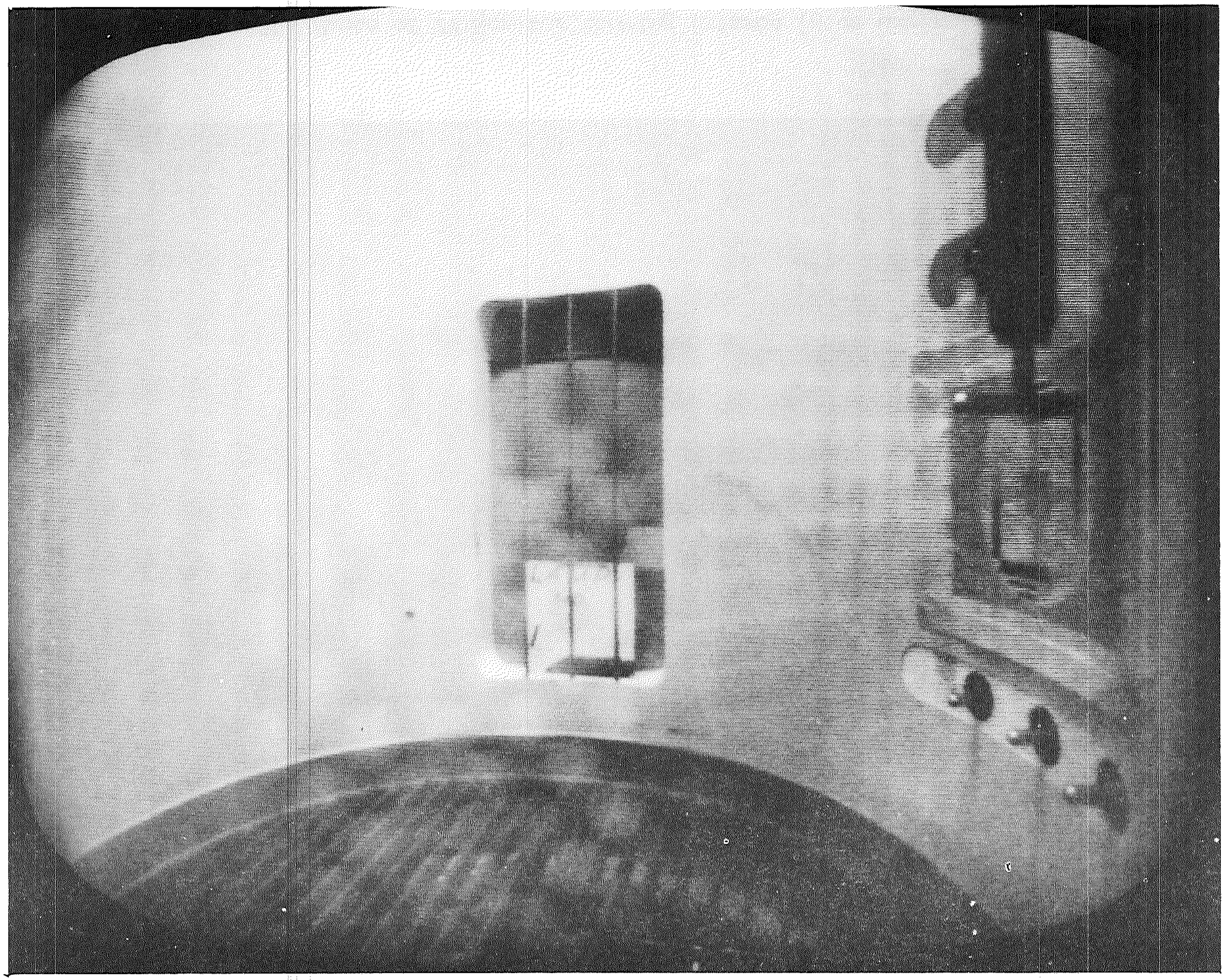


Figure 60 Photo of TV Monitor With Primate Removed
(Side Camera)

Following the above test, the top-mounted TV system was demonstrated. The top TV system is mounted on an inclined plane, 10° off of horizontal on the top surface of the cage. A Cohu 2000 series, 945 line, camera fitted with a Cohu 10:1 zoom lens covering 15 mm to 150 mm focal length was integrated with a model L001 P.F. Research pan and tilt unit. This device allows 350° of pan and $\pm 350^{\circ}$ of tilt. Also incorporated into the pan and tilt unit is a Mylar film drive.

Controls for the system are at the control console on the video system panel as shown in Figure 61. The lens is servo-driven for focus, iris, and zoom. Vidicon adjust control is provided in addition to the lens focus control to provide extra adjustment for high-resolution viewing. A joy stick control is provided for pan and tilt directional drive. All drives are fitted with slip clutches, limit switches, and mechanical stops to prevent system damage.

The system was designed to meet the operational goal of 0.010" resolution at the cage floor, and cage walls to the height of the water lip device. Test procedures called for all system controls to be operated through their full range and under each possible illumination condition.

A standard TV test pattern was placed on the cage floor for resolution and tone measurement. Each illumination lamp was turned on in sequence and the TV system adjusted for the best performance in both the high resolution and wide angle lens positions. A black and white photo was taken of the picture as received on the TV monitor. Table 7 gives the results of this test series.

The TV picture with the night lights on at the 28 VDC power level, lens system at f/2.8 and system focused for high resolution was very poor. No detail viewing was possible.

The TV system was positioned to see the feeder lip device and zoomed to high resolution. The results were very good as can be seen in Figure 62. Dirt on cage liner is apparent near the lip device.

The pan and tilt system was operated through the zoom (near and far), focus, iris and vidicon adjust. All functions performed as required. The Mylar drive system was operated and performance was normal.

In summary, top TV system performance was very good. The resolution requirement of 0.010" was met with just one illumination lamp on. As the other lamps were energized, the picture quality improved in both resolution and shades of gray. The best of the test series is shown in Figure 63 and 64. All camera control functions worked well. The pan and tilt drive performance was good. If, under drive conditions, the top TV assembly hit the top air duct, the drive slip clutches automatically prevented damage to the system. By watching the TV monitor, when the system

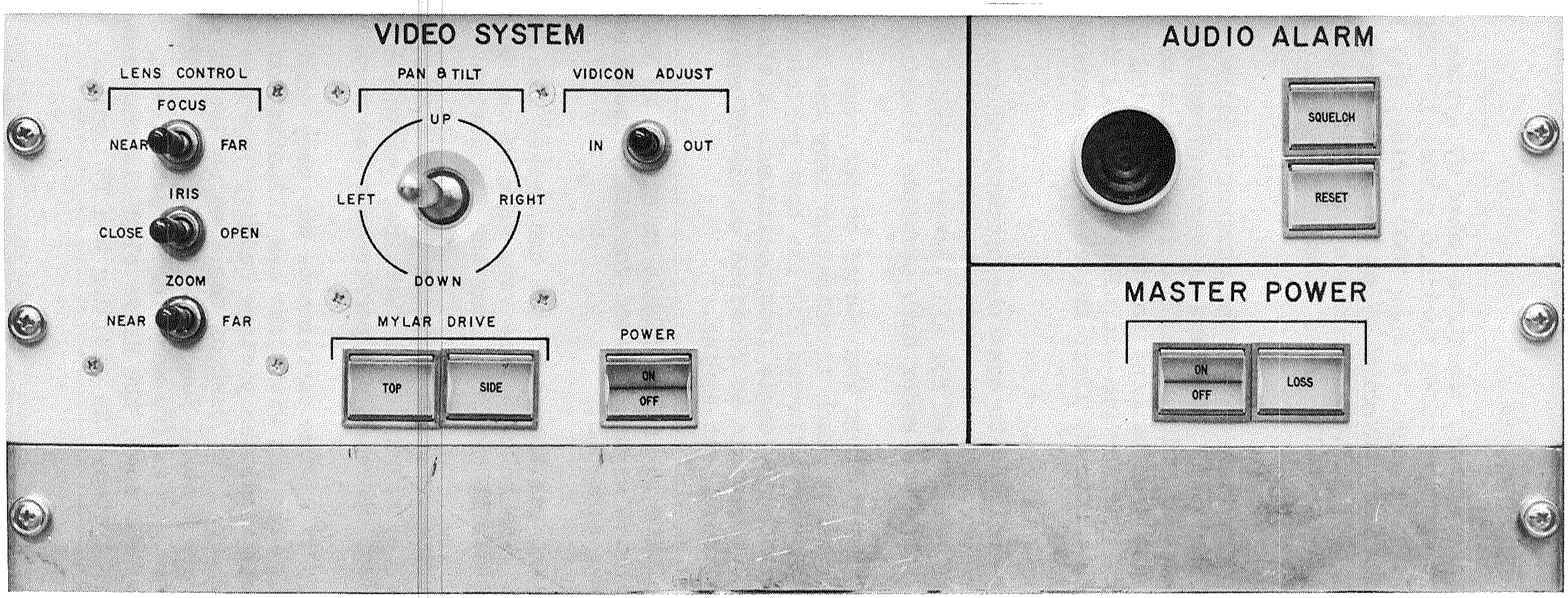


Figure 61 Video System Controls

TABLE 7

Top TV Demonstration

No. Lamps	Zoom Position	Picture Quality	TV Test Pattern Results
1	High resolution	Good	Better than 500 lines. 4 shades of gray. 0.010 resolution.
1	Wide angle	Good	Good ability to scan cage floor area. Mylar protective screen visible. 3 shades of gray.
2	High resolution	Very good	600 lines. 0.010" resolution. 5 shades of gray.
2	Wide angle	Good	Mylar protective screen visible. Good floor detail. 3 shades of gray.
3	High resolution	Very good	600 lines. 0.010" resolution. 6 shades of gray.
3	Wide angle	Good	Mylar protective screen visible. 3 shades of gray. Good floor detail.
4	High resolution	Very good	500 lines. 0.010" resolution. 7 shades of gray. Very good detail.
4	Wide angle	Good	Mylar protective screen visible. 3 plus shades of gray. Very good floor detail.

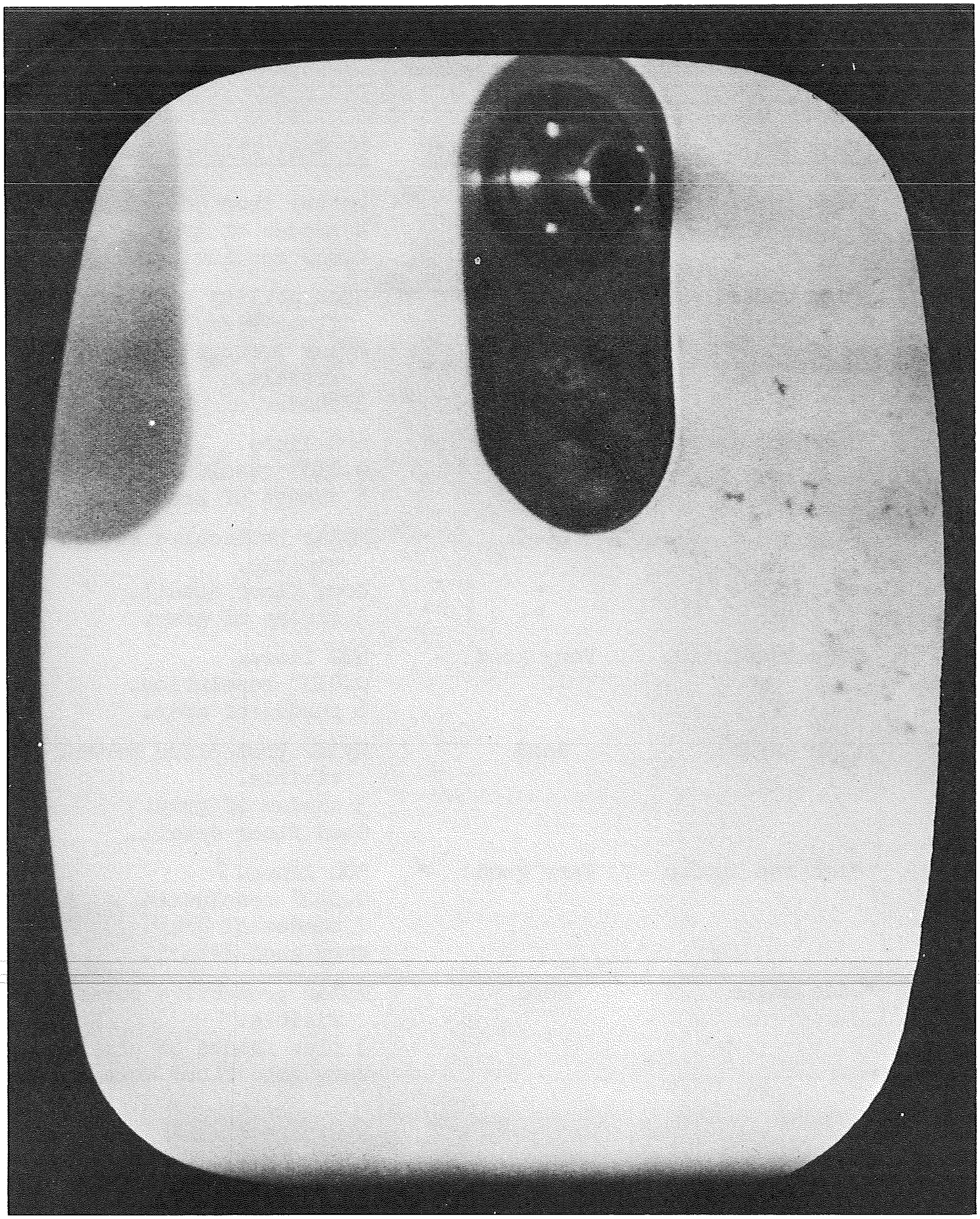


Figure 62 Photo of Feeder Lip Device (Top Camera)

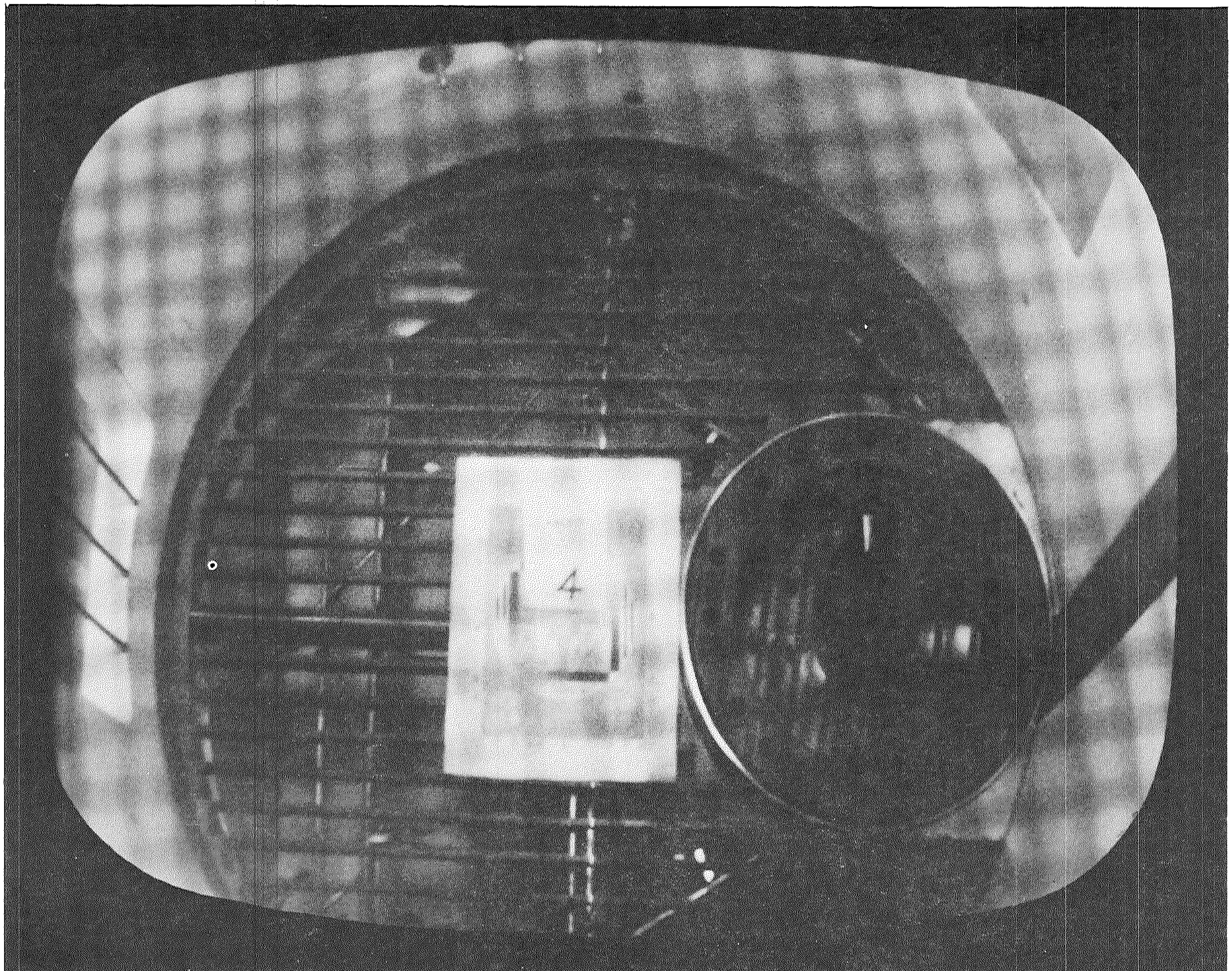


Figure 63 Photo of TV Monitor (Top Camera - Wide Angle)

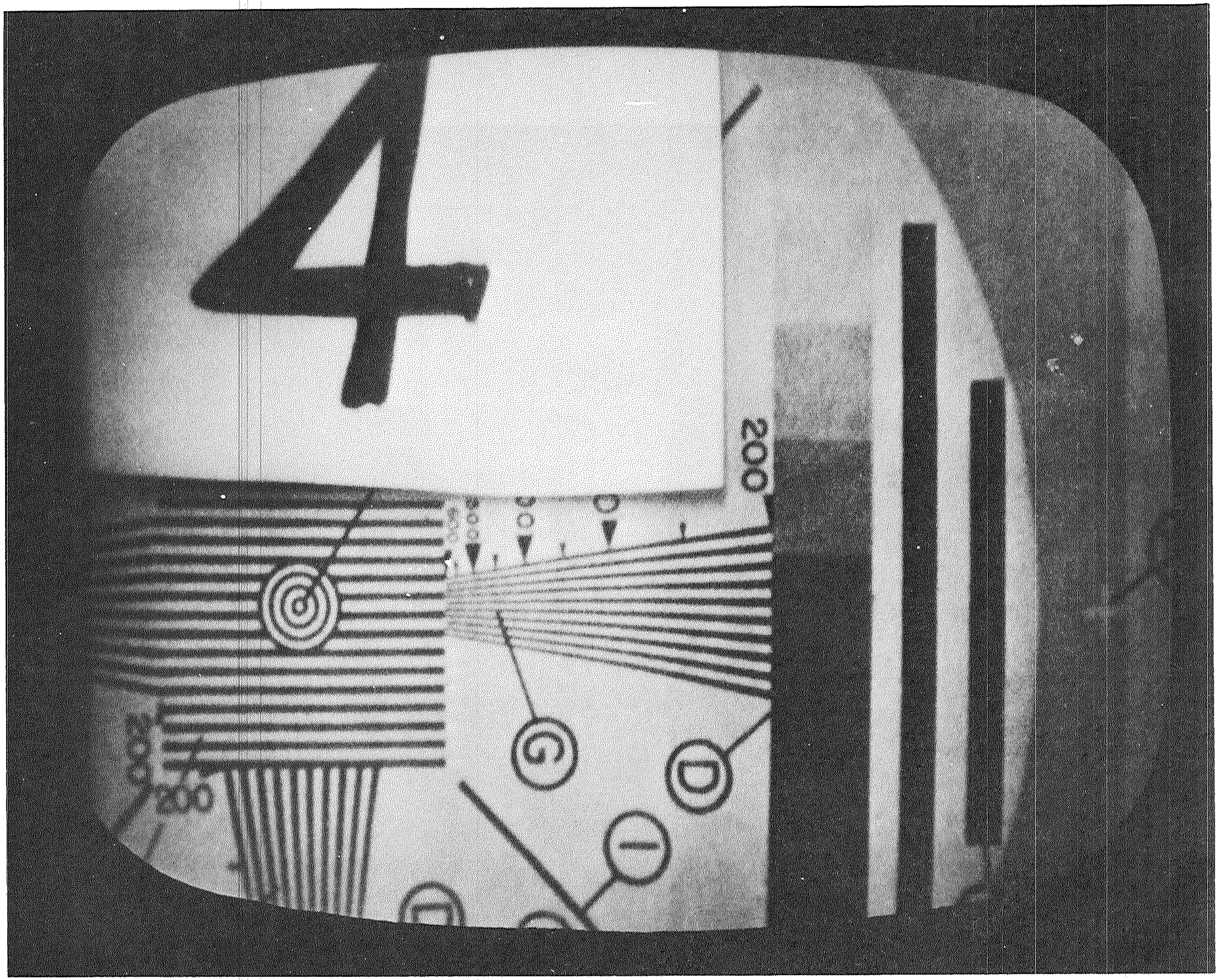


Figure 64 Photo of TV Monitor (Top Camera - High Resolution)

did hit an obstruction, it was easy to drive the system the other way and move away from the obstruction to another viewing angle. It was also determined by the test series, that night light viewing is not possible.

Electromagnetic interference evaluation-biomedical and activity monitoring subsystems.- The purpose of this test was to evaluate the capability of the biomedical and activity monitoring subsystems to function satisfactorily while being subjected to interference from complex electromagnetic fields.

A functional configuration of the subsystem, including the ECG and temperature transmitters, antennas, receivers, demodulators, magnet, magnetic pick-up coils, photo-cell sensor, associated circuit cards, cabling, and a full-scale metal mockup of the primate cage, was set up in a shielded enclosure having an electromagnetic attenuation of 80 dB, in the LMSC Space Systems Division Environmental Test Laboratory.

The biomedical and activity monitoring subsystems were energized and adjusted to obtain normal performance when displayed on an eight channel analog recorder. The following parameters were recorded: simulated speech, photo sensor, field-strength activity, and magnetometer events; and field-strength activity, temperature, ECG and magnetometer analog traces.

The system was then subjected to electromagnetic interference (EMI) tests CS01, 02, 03 and 04, and RS01, 02 and 03 in accordance with MIL STD 461A (1 Aug. 1968) and MIL STD 462 (31 July 1967) while in periodic operation in accordance with the following procedures:

1. Photo-sensor Activity

   Move the hand between the light source and photosensor. Note that a +5 volt digital pulse is produced for each interruption of the light beam. Perform this procedure for outputs 1 and 2.

2. Voice Operated Relay

   Speak in a normal voice at distances of one to five feet from the microphone. Note that a digital output is produced, that the +5 volt level is held while speaking, and that the level is held for 3.5 seconds after speech is stopped. Perform this procedure for outputs 1 and 2.

3. Magnetometer

   Analog: Move a small magnet in various patterns, within the space of the cage. Observe that an analog signal, maximum of $\pm$ 2.5 volts varies about the +2.5 volt reference line. Perform this procedure for outputs 1 and 2.

Digital: As the above procedure is being followed, observe that digital +5 volt pulses are produced as the result of very small movements of the magnet. Perform this procedure for outputs 1 and 2.

4. Receiver Activity

Analog: Move one or both transmitters about within the cage. Note that the analog output varies between zero and +5 volts, depending on the proximity of the transmitters to the antenna assembly. Perform this procedure for outputs 1 and 2.

Digital: As the above operation is performed, note that one millisecond positive voltage pulses are produced as the analog output swings through the approximate center of its output range (+2.5 volts). Perform this procedure for outputs 1 and 2.

5. Temperature Analog

Place the temperature transmitter in a temperature controlled water bath (glass or plastic container) within the cage. Observe that the output varies between zero and +5 volts, depending on the temperature range covered. Perform this procedure for outputs 1 and 2.

6. ECG Analog

Place the ECG transmitter inside the cage. Note that the output is a steady signal at the mid-point of the output range (about +2.5 volts). Now apply a 1 millivolt, 1 Hz triangular wave to the electrodes of the transmitter. Observe that the triangular move is reproduced at the output, showing approximately a zero to +5 volt range. Perform this procedure for outputs 1 and 2.

7. Cueing Amplifier

The cueing amplifier may be demonstrated by using an audio oscillator as a signal source, and observing that the signal is amplified and reproduced at the loudspeaker. If an oscilloscope is used, it will be observed that a one volt input signal produces a ten volt signal across the loudspeaker terminals.

8. Animal Vocalization Amplifier

The vocalization amplifier may be demonstrated by speaking into the microphone and noting that the sound is amplified and reproduced at the loudspeaker. The gain control may also be demonstrated by setting it to various levels.

The results of these tests are summarized below:

<u>CS01-Conducted Susceptibility 30 Hz to 50 K Hz</u>

Upon injection of power at levels ranging from approximately 100 mv to 1.2 v on +12V, -6V and -12V DC power lines, disruption of system was noted on all channels. As a result, 100 uf capacitors were installed in each of the DC power lines (+12V, -6V, -12V, and +5V). Testing was re-started and the following results obtained:

Power Lead	Frequency or Frequency Range	Injected Power Level	Channel Disrupted
-12V	3K Hz - 40 K Hz	1.0 v	Magnetometer
-12V	30 Hz - 250 Hz	0.4 v	Field Strength Activity
-6V	25 K Hz - 40 K Hz	100 mv	Temperature
-6V	30 Hz - 20 KHz	100 mv	Temperature and ECG
+5 V	2.5 KHz	300 mv	Magnetometer and temperature
+12V	4 KHz - 50 KHz	300-500 mv	Magnetometer, ECG, Temperature, and Field Strength Activity
+12V	50 Hz - 4 KHz	100 mv	Temperature and Field Strength Activity
+12V	30 Hz - 50 Hz	200 mv-1.2 v	ECG, Temperature, Field Strength Activity and Voice Events

CS02-Conducted Susceptibility 50 KHz to 400 MHz

Various power levels were again injected on each of the four DC powers. One of the operational amplifiers latched into an extreme position, but this was found to be only an adjustment problem. The following noise effects were observed:

Power Lead	Frequency or Frequency Range	Injected Power Level	Channel Disrupted
-12V	50 KHz - 400 MHz	100-200 mv	Magnetometer
-6V	80 MHz - 170 MHz	100-200 mv	Magnetometer
	400 KHz - 50 MHz	100-200 mv	Magnetometer
	50 KHz - 400 KHz	200 mv	Magnetometer, ECG, Temperature, and Field Strength Activity
+5V	250 KHz - 170 MHz	100-400 mv	Magnetometer
	60 KHz	300 mv	Magnetometer
+12V	400 MHz	40 mv	Magnetometer
	200 MHz-300 MHz	100-600 mv	Magnetometer
	60 MHz-170 MHz	30-50 mv	Magnetometer
	7 MHz-60 MHz	5 - 10 mv	Magnetometer
	120 KHz-7 MHz	10-50 mv	Magnetometer
	50 KHz - 120 KHz	20 mv	Magnetometer, ECG, Temperature, and F. S. Activity

RS01-Radiated Susceptibility 30 Hz to 30 KHz

The system was subjected to a radiated magnetic field in the frequency range of 30 Hz to 30 KHz. The field intensity ranged from 27.5 X 10^{-5} Teslas at 30 Hz to 5 X 10^{-8} Teslas in the range of 2.5 KHz to 30 KHz. Some degradation was noted in the magnetometer output from 30 Hz to 80 Hz. In addition, the sound operated relay functioned incorrectly from 30 Hz to 40 Hz.

RS02-Radiated Susceptibility, Magnetic Induction

Number 14 gauge wire was wrapped, at one turn per meter, each in turn around the main power cable, the cable from power supply to input and output connectors, the cable from the card to input and output connectors, and the cables from the power supply to the receivers. In addition, wire was looped each in turn around the card rack (in two directions) and the primate container. Twenty amps of first 60 cycle and then a 10 μsec. pulse was applied to each setup as listed above. No degradation of system performance was noted.

RS03-Radiated Susceptibility, 14 KHz to 10 GHz Electric Field

In the range from 14 KHz to 35 MHz, the system was placed between two parallel copper plates spaced 19 inches apart. The voltage between the plates was fixed at 0.5 volts. Some slight magnetometer reaction was noted from 80 KHz to 100 KHz. In the range from 35 MHz to 10 GHz, power was applied to various antennas to maintain a field of 1 volt per meter over the system. Reaction by the magnetometer was noted to be severe from 8 MHz to about 350 MHz. No other degradation was noted.

CS03 and CS04- Conducted Susceptibility 30 Hz to 106 Hz Intermodulation and Rejection

Both CS03 and CS04 were conducted on each of the two receivers alone. Because of the similarity between CS03 and CS04, the steps for each were intermixed. Receiver 1 experienced no intermodulation response in the range of 10 MHz to 1.1 GHz. In addition, Receiver 1 experienced no spurious responses in the range 2 MHz to 2.1 GHz.

Receiver 2 experienced no intermodulation response in the range 10 MHz to 1.1 GHz. Spurious responses were noted in Receiver 2 and were as follows:

Frequency of Spurious Response	Spurious Response Rejection Ratio
23.046 MHz	27.4 dB
70.914 MHz	37.4 dB
173.76 MHz	33.2 dB

From these tests, it was apparent that the magnetometer was most susceptible to electromagnetic interference. Attempts at reducing its susceptibility were unsuccessful and as a consequence, this feature of the biotelemetry system was not used. There were two other activity measuring systems, i.e., photocell and field-strength and a decision was made to rely upon them to determine primate activity.

It was also apparent that over a wide frequency range, if injected power levels remain below approximately 100 mv, functions other than the magnetometer were not affected by these tests.

Behavioral programmer demonstration.- The purpose of this test was to evaluate the capability of the behavioral programmer to function satisfactorily while connected to all of its interfacing TFDM and control console equipment.

The hardware under test consisted of the Government-furnished behavioral programmer (See Figure 65), behavioral task panel, exercise device, feeder, purge fan, illumination system, noxious stimulus jets, and elements of the water system which interface with the behavioral programmer.

The test commenced with a demonstration that the TIM, ILK, VIG and EXC tasks were presented properly on the behavioral task panel in the TFDM. Following the proper responses to these tasks, it was observed that food and/or water was made available as indicated by the appropriate cue lights. Upon actuation of the food and water lip devices, an observation was made of feeder and waterer operation and reset. Upon receiving the AVD warning tone, both automatic and manual operation of the noxious stimulus jet and purge fan system was observed. Programmer control over the illumination system was also demonstrated.

During the course of the demonstration, the following modifications were made to the programmer and to an associated LMSC logic card to achieve complete compatibility:

1. Installation of a wire between programmer pins GG and HH on connector J2.
2. Removal of a temporary jumper between pins 31 and 34 of LMSC logic card B11.
3. Wiring of +28 VDC to programmer J3-p for the water cue lights.
4. Installation of a 3.2 uf capacitor on programmer board #1, module A13, between pins 17 (high) and 2 (gnd).
5. 180° rotation of the programmer "Lip Switch Block" in/out switches for food and water.

Following completion of the test, the following anomolies were evident:

1. Noise spike on ILK input line results in a wrong count for success.
2. Day cycle time falls short.
3. Programmer avoidance task appears to work correctly, but LMSC logic card did not function satisfactorily in the automatic mode.
4. Upon activation of the feeder or water system when reward is available, the programmer removes the arming signal immediately instead of waiting for the food tablet or water dispensed signal.

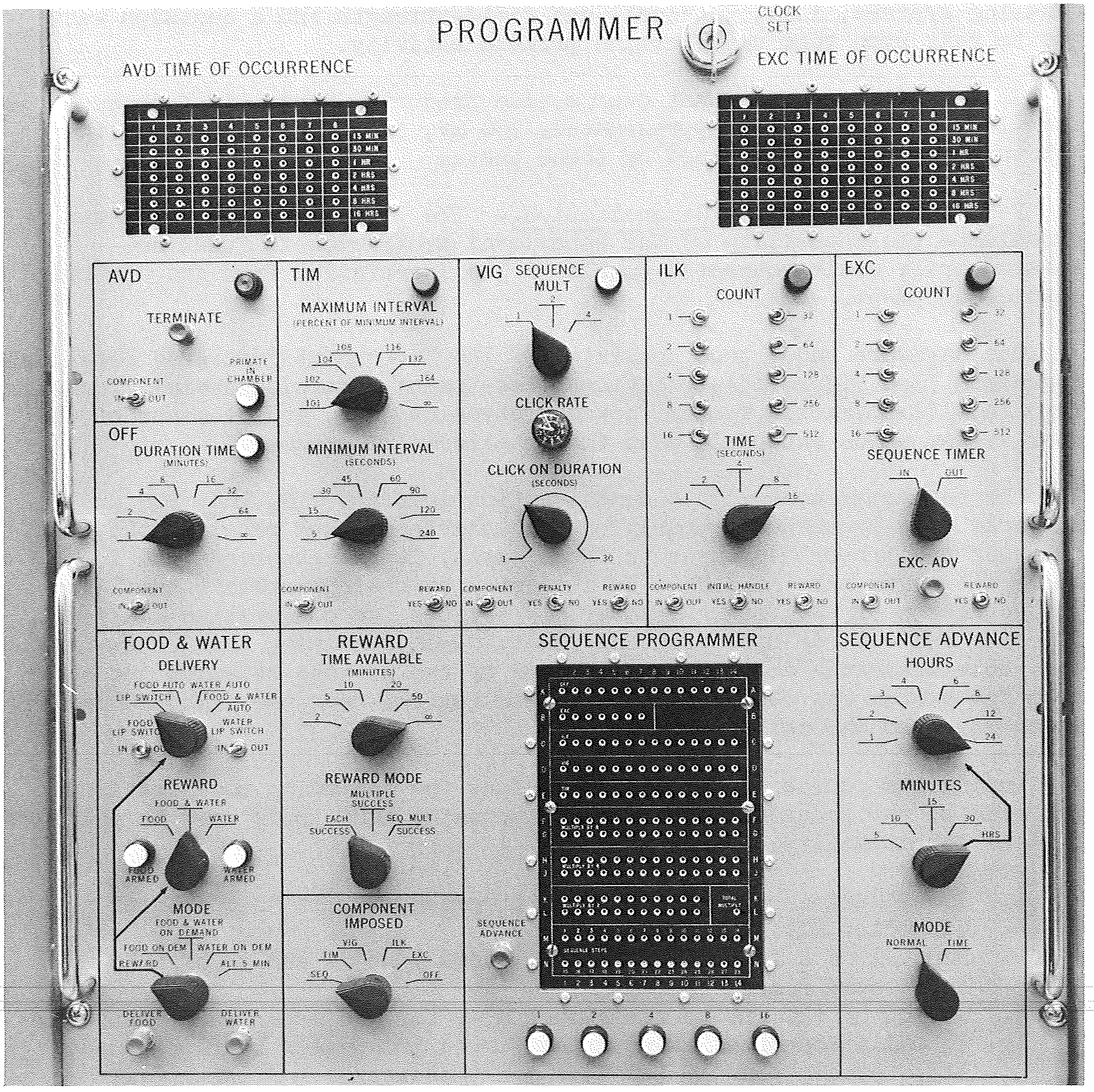


Figure 65 Behavioral Programmer

Anomolies 2 and 3 were corrected prior to the acceptance test by (1) replacement of a module in the timer count-down clock, and (2) repair of the logic card. Items 1 and 4 were corrected prior to delivery of the hardware by the addition of resistors and capacitors to suppress the noise spikes responsible for the incorrect responses.

Acceptance Test

Acceptance testing for the TFDM was of two types (1) component functional verification and (2) the technical feasibility demonstration model acceptance test.

Component acceptance tests.- The component acceptance tests provided a functional check on equipment received from suppliers, in order to verify its adequacy for use in the TFDM. Much of the vendor hardware was acceptance tested during the system test phase of the program. Two formal component acceptance tests were conducted. The first of these was the operation of the Rotron MS 4501 fan to insure proper freedom of rotation, direction of rotation and electrical power requirements. Operation of the fan proved satisfactory. This fan is used in the 200 cfm air circulation loop.

The second formal test was conducted on the Joy 500702-6020 fan. Again the unit was checked for freedom of operation, direction of rotation, general performance characteristics, and electrical interfaces. This fan is the 2000 cfm purge fan; it operated satisfactorily.

On purchased items such as valves, solenoids and accumulators, vendors were required to supply acceptance test reports of the hardware prior to shipment to LMSC. This test data is filed within the TFDM project logbook and was delivered with the hardware. The master copy has been retained by LMSC Product Assurance.

Technical feasibility demonstration model acceptance tests.- This test was designed to demonstrate the satisfactory performance of the complete TFDM and its associated control console, and the final compatibility of the TFDM and controls with the primate. The test formed the basis for acceptance of the hardware under contract NAS 1-8200.

The system acceptance test was divided into two phases. Phase 1 was the biomedical and activity monitoring system demonstration, prior to starting the formal acceptance test.

The biomedical and activity monitoring test was to be conducted by placing the temperature transmitter in a temperature-controlled water bath located within the cage. The water bath was then to be moved about within the cage to simulate various primate positions relative to the antenna. The ECG transmitter was also to be placed in the cage and a one-millivolt, one Hz triangular wave form applied to the electrodes of the transmitter. All output data was recorded on a Sanborn recorder. The photo-sensor, magnetometer, and field strength activity monitor data were to be handled in the same manner.

The NAMI primate was to be used as the test subject for the 14-day test period. The primate was not required to operate the behavioral task panel or exercise device during the test, but efforts were to be made on a non-interference basis to train him on these devices by NAMI personnel.

The test was to be conducted in a specially air conditioned room which housed the TFDM with interconnecting electrical cables to the control console in the adjacent room (See Figure 66). The TFDM in the acceptance test configuration is shown in the frontispiece of this report.

A test log book was to be maintained during the 14 day test period and according to the recording schedule shown in Table 8.

A set of test termination considerations were developed, and should any of the conditions indicated below arise, the LMSC program manager, test director, and the NASA program manager were to caucus and determine a course of action. (In an emergency, such as fire, the test director had the authority to terminate the test.)

- If the primate's well-being is in jeopardy (including animal failure to eat or drink for a period of 24 hours).
- If the cage air bleed flow drops below 6 cfm.
- If cage temperature cannot be maintained within the 70-80^{o} range.
- If the feeder fails to deliver a food tablet following four successive actuations of the feeder lip device.
- If the waterer fails to deliver water following four successive actuations of the lip device.
- If cage ammonia concentration exceeds 25 mg/m^3.
- If cage air total organism count exceeds 200 org/ft^3.
- If water supply total organism count (upstream of delivery filter exceeds 100 org/ml).

If the test is terminated for any of the above reasons, corrective action was to be taken and the test continued to achieve a total of 14 days test time.

Final OPE system checkout was conducted during the last week in May, 1969. The feeder was filled with approximately 100,000 food tablets. The water system was filled with approximately 100 pounds of filtered, heat-sterilized tap water, and test samples sent to the bacteriological laboratory.

The noise at the cage floor, produced by the 200 cfm fan, was 90 dB and was not acceptable. A silencer was fabricated and installed on one of the two fans in the system. This resulted in a reduction in sound level to 82 dB which was approved for the purpose of acceptance testing.

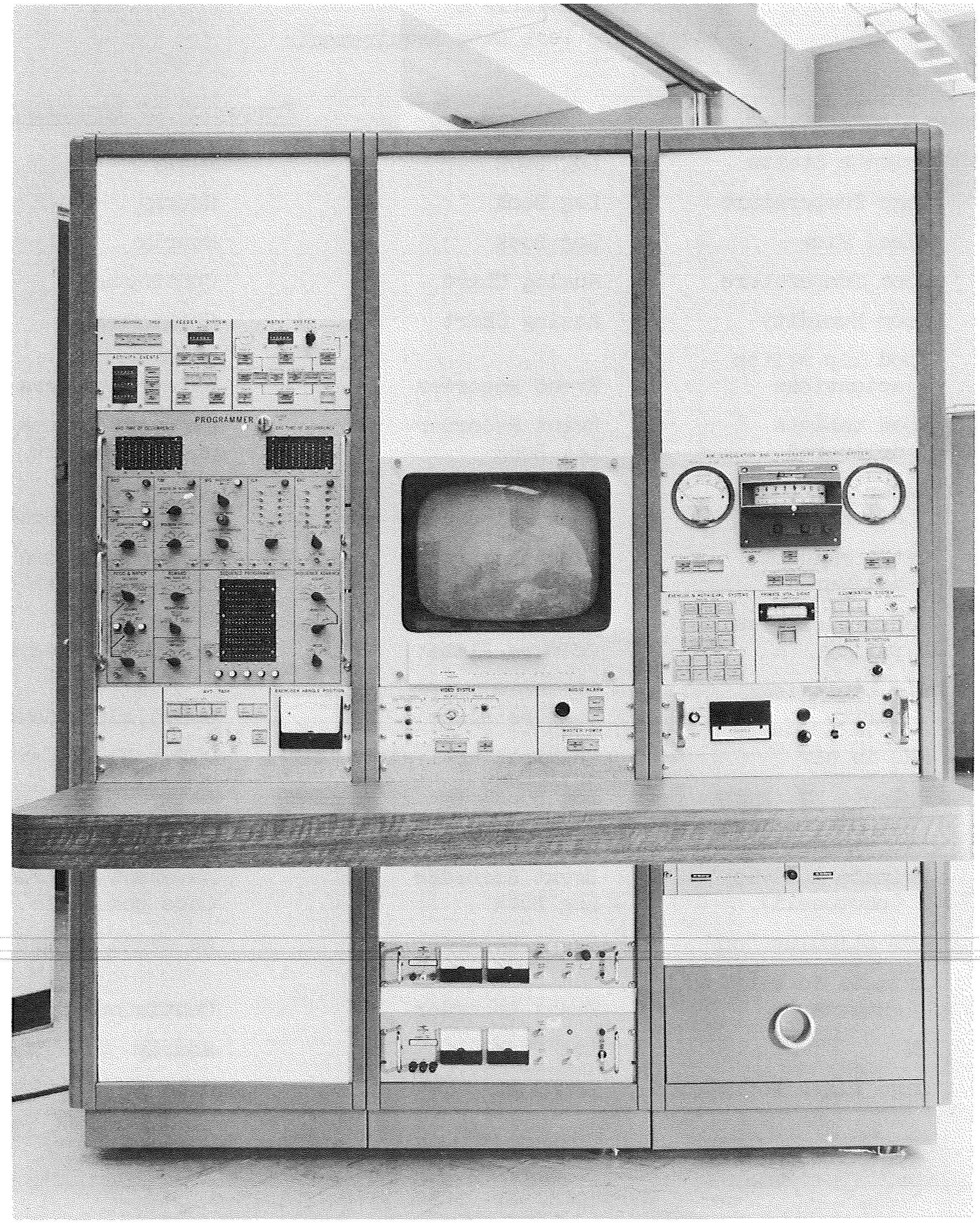


Figure 66 TFDM Control Console

Table 8
Acceptance Test Data Requirements

Item	Record	Frequency of Recording
Primate Status	Log Book	Daily
Cage Temperature	Log Book	Hourly
Bleed Flow	Log Book	Hourly
Room Temperature	Analog Chart	Continuous
Room Humidity	Analog Chart	Continuous
Food lip switch actuations	Event Recorder	As event occurs
Food tablets delivered	Event Recorder Log Book	As event occurs Once per shift
Water lip switch actuations	Event Recorder	As event occurs
Water aliquots delivered	Event Recorder Log Book	As event occurs Once per shift
Water biological purity	Culture Plate	0,2,5,10,14 days
Air biological purity	Culture Plate	0,2,5,10,14 days
NH_3 in air	Chemical analysis	0,2,5,10,14 days
Primate Mass	Log Book	Daily
Primate Vocalization	Magnetic Tape	As event occurs
Primate Activity (photocell)	Event Recorder Log Book	As event occurs Once per shift
AVD stimulus "on"	Event Recorder	As event occurs
Primate in retrieval canister	Event Recorder	Continuous
TV	Log Book	Hourly
Cage Liner Retraction	Log Book	Once

On 2 June 1969, laboratory results showed the first drinking water system fill was contaminated with 56 organisms/ml of water. The water system was drained and three gallons of a water sodium hypochlorite solution injected into the system. This solution under 10 psig pressure was allowed to stand in the system for one hour. The solution was then withdrawn and the procedure repeated three times. The complete system was then rinsed with sterile water three times, using two gallons of water for each rinse. The water system was re-filled with filtered and sterile water, and samples sent to the laboratory for analysis; these microbiological tests were negative.

Prior to the start of the acceptance test, the detail countdown procedures were used to check the operation of each subsystem to insure readiness and satisfactory performance. As a result of this complete system checkout, the following eight discrepancies were noted:

- o The air flow out of the cage representing ECS flow is low (8.5 cfm) when compared with the 11.5 cfm flow into the cage.
- o The 400 cycle power source for the 2,000 cfm fan is not operative.
- o Mass measurement readings are erratic.
- o The 400 cycle power failure alarm monitor is not operative.
- o The "primate in canister" indicator system is erratic in operation.
- o The TV power on-off switch is not wired to the panel.
- o The photocell light source transmits too much visible light and the sensor is too sensitive.
- o The 2000 cfm run time switch is not wired.

A joint NASA/LMSC decision was made that the acceptance test would be run for a ten day period in the initial configuration, at which time the test would be terminated and the load cells from the mass measurement system would be removed and returned to the vendor for service. The discrepancies noted in the photocell activity monitor and "primate in canister" systems were also to be corrected. Upon completion of the required changes, the acceptance test was to be restarted and continued for an additional 48 hours during which time the changes were to be observed to operate in a satisfactory manner. During the shut down time and the 48 hour test period, samples from the water storage tanks were to be continued on a daily basis. It was not a requirement to do either bacteriological or chemical analyses of the cage air during the 48 hour re-test period.

On the morning of 12 June 1969, the OPE/TFDM acceptance test countdown started. The detail countdown checked out every operational function of both the TFDM and control console systems. As each step was taken, system performance was noted in the remarks column of the countdown procedure. A part of this procedural countdown included the demonstration of the biomedical monitoring system prior to placement of the primate into the cage. This test first demonstrated that signals from photocell activity, voice events, temperature ECG, field strength activity and magnetometer activity occurred on both sets of isolated outputs. The same biomedical system operating procedure was used as had been used during the EMI tests. The temperature transmitter was immersed in a temperature-controlled water bath and a triangular-wave generator was used as the input to the ECG transmitter.

Following the demonstration of successful operation with other TFDM systems inoperative, all major items of TFDM equipment were operated with the noted resulting effects on the biotelemetry system:

Equipment Operated	Effect on Biotelemetry System
12 cfm fan	None
200 cfm fan	None
Temperature controller	None
Illumination system	Transient disruption of all biotelemetry channels during switch-on of lamps
TV power supply & controller	Transient magnetometer disruption during start-up.
TV monitor	None
TV iris control	None
Vidicon in and out	ECG noise
TV zoom and focus	None
Pan and tilt	ECG, temperature, and field-strength noise.
Mylar drive	Noise on magnetometer, ECG, temperature, field-strength activity, and voice-operated relay channels.
Mass measurement system	None
TIM, ILK, VIG levers and exercizer	Noise on magnetometer, ECG and voice-operated relay channels. Magnetometer was affected by metal rod being used to operate levers. Voice operated relay was affected by operating noises.
Feeder and waterer lip devices	Noise on magnetometer, ECG and voice-operated relay channels during actuation.
10 KC warning tone	Voice-operated relay actuation.
Noxious stimulus jets	Magnetometer and voice-operated relay actuations.
Exerciser retract	Noise on magnetometer, ECG, temperature, voice-operated relay and field strength activity.
Cage liner roll-up	Noise on all channels.

After the above testing was completed, the water bath temperature was increased from 35°C to 39°C to demonstrate the response of the temperature transmitter. As a result of this 4°C temperature increase, the voltage output decreased by 2.1v on the temperature channel.

While the countdown was in progress, the NAMI primate was given a careful examination by a NAMI veterinarian and was found to be in excellent health and ready for testing. The complete countdown was completed and the primate placed in the cage assembly on 13 June 1969 for the start of the 10-day test.

Test personnel were on duty 24 hours a day, seven days a week. Each test event was recorded in the test log and unplanned events were recorded on a separate form. The primate, while familiar with the cage, feeding and watering devices, was unfamiliar with the behavioral task program and exerciser, yet within the first few days of testing was working the behavioral task program for food and water reward. Through careful conditioning by the NAMI technician, within a few days the primate was also completing several up and down cycles on the exercise device.

At the completion of the 10-day test period, the retrieval system was operated automatically, placing the primate in the retrieval canister. Since, at the time of this retrieval, the louvered piston (See Figure 63) was mounted to the retrieval piston actuator, lockup of the piston into the retrieval canister was not attempted. The retrieval sequence was completed without incident. The 10-day test was completed on 23 June 1969.

During the 10-day test period, the following nine "unplanned events" were experienced:

- The "water aliquot full" indication did not appear on the control console reliably. This problem was cleared up by slightly increasing the pressure on the water delivery system to ensure that the water aliquot microswitches were fully depressed. No further problems were encountered in this area.
- The "primate in canister" light came on without the animal being present in the canister. This problem was diagnosed as a temperature effect on the presence sensor, and led to a modification plan for the end of the ten-day test.
- The programmer prematurely switched from the "day" to the "night" cycle. Override capability on the Lockheed console was exercised to reinstate the "day" cycle manually. This problem was repeated at various times during the test and was corrected manually.
- The TIM handle on the behavioral task panel continued to give an "activated" signal after being released by the primate. The TIM lever-switch mechanism was inspected from the back of the task panel. It was found that the microswitch actuators were not properly engaged in the lever and were providing a continuous switch closure. The engagement was restored to its proper configuration and the problem did not repeat. Even though the problem

could not be repeated by violent motion of the handles, the engagement of the switch actuators was made more positive after the 10-day test as an additional reliability measure.

- About a week after initial sterilization with a sodium hypochlorite solution and charging of the water tanks, the water supply was found to be contaminated with 300 organisms/ml. A separate sterile water supply was set up to allow the test to continue, and the primary system was re-sterilized using a 90% CO_2 - 10% ethylene oxide mixture. The tanks were then recharged with sufficient water for the remainder of the test and daily water samples were taken. No further problem was encountered with the water supply.

- The primate appeared to be shocked when he had his hand on the VIG lever and his mouth on the water lip device. A voltage measurement showed some parts of the behavioral tank panel to be approximately 0.8 vdc above ground. Temporary grounding jumpers were installed and the unit was permanently grounded after the ten-day test. This problem did not repeat.

- Periodically, the feeder was not armed upon game success even though the feeder cue light did come on.

- The programmer gave a reward when on the EXC component, with the EXC handle in the "down" position when the animal actuated any of the behavioral panel levers.

- The audio alarm system sounded due to a high cage temperature event (78.5°F vs. a maximum set point of 78°F). The heater system was shut off. The event was caused by heat from motion picture flood lights near the TFDM. The situation was continuously monitored to ensure not exceeding 80°F in the cage. The problem did not repeat after the flood lights were removed.

At this point, in accordance with the NASA/LMSC revised test plan, the primate was removed and the waste management system separated from the TFDM to gain access to the mass measurement load cells. The load cells were removed and sent to the vendor with the readout system for complete check and calibration under LMSC surveillance. The load cells were found to be in good working order and were returned to LMSC. A parallel investigation at LMSC revealed a mechanical interference between the floor, its support structure and interconnecting tubing. The complete floor subsystem was removed. The outer ring to which the floor attaches was rubbing at several points on the basic TFDM structure. This ring was cut at four points, material removed and the ring rewelded and ground smooth. This reduced diameter of the ring, allowing increased clearance between the ring and the structure. All interconnecting tubing was remounted to provide more flexure, reducing any hysteresis which could be introduced at this interface.

The system was reassembled and a test run conducted using calibrated weights, with the following improved results:

Floor Test Point	Actual Weight (lb)	MMS Reading (lb)
1	13.0	12.98
2	13.0	12.97
3	13.0	12.94
4	13.0	12.93
5	13.0	12.97
6	13.0	12.96
7	13.0	12.96

Also, during this period, the complete TFDM cage assembly and ducting was checked for air leaks, and non-toxic, non-flammable potting compound used to fill cracks and voids in order to reduce air flow loss and to better balance the 12 cfm inflow and outflow design goal. The best balance achieved was an inflow of 11.5 cfm and an outflow of 9.0 cfm.

The photocell light source was filtered and the photocell itself was modified making it insensitive to activities other than cutting the light beam by installing it in a small-aperture tube. The system was checked and performance was satisfactory.

Two copper rings were added to the interior of the retrieval canister to improve the reliability of the "primate in canister" signal. Primate contact with these electrodes would activate the system. The system was checked and operation was improved.

During the ten day test, the AVD portion of the behavioral program was tried. The primate would go to the top of the cage, but refused to enter the retrieval canister. The 2000 cfm fan was operated and the response of the primate was to climb on the exerciser device which gave him some sanctuary from the air flow. The fan was shut off and the primate then entered the canister for the first time. After returning to the cage, the primate was offered food and water rewards, but refused. The floor jets were energized a second time and the 2000 cfm fan actuated. The primate repeated entry into the retrieval canister and the noxious stimulus system was shut down. The primate then returned to the cage after spending some time in the canister. Somewhat later, the primate voluntarily went into the canister and was given a reward. After this series of tests, the primate showed considerable interest in the retrieval canister, but had difficulty in entering it. Consequently, a steel ring was fabricated and installed in the lower end of the retrieval canister to act as a hold.

The 48 hour test, the last phase of the acceptance test, was started 27 June 1969. Animal insertion into the cage system took place at 2015.

During the test, just prior to the recovery sequence, the avoidance task was initiated. The floor jets were energized and the floor actuated with the 2000 cfm fan operating. The primate climbed on to the exerciser. The system was shut down, the exerciser retracted and the above sequence repeated. This time the primate retreated directly to the retrieval canister. All noxious stimuli were shut down and the food and water lip devices armed for reward. This was the first time the primate had responded to noxious stimuli in the desired fashion. One hour later, the avoidance task was energized through the behavioral programmer. The primate did not respond to the 10 kc tone. At that point in time, the floor jets were manually started, the floor actuated and the 2000 cfm fan was run for 36 seconds. The primate responded to the air jets by going directly into the retrieval canister and stayed there.

At 2055 on 29 June 1969, primate retrieval was accomplished, completing the acceptance testing of the TFDM.

The test was successful with the following exceptions:

- In checking redundant and override functions from the control console, it was observed that the 200 cfm fan "low ΔP" light did not come on when the fan was shut down. Several checks were made of the equipment, and it was found that by disconnecting the tube on the high pressure side of the ΔP switch, the switch bled down and did give a "low ΔP" alarm. This indicated some blockage of the tube; however, no blockage was evident in the exposed tubing.

- During primate retrieval, one tether line separated from its negator spring assembly. The operations of cage rollup and deployment were not adversely affected by loss of one tether.

- During primate retrieval, the piston head failed to seat in the retrieval canister. This problem was traced partly to piston misalignment, caused by changes in the floor mounts made to correct the mass measurement system. A contributing factor was insufficient chamfering of the latches to accommodate misalignment.

The primate's accommodation to the TFDM was excellent and he learned to work the behavioral program for food and water.

The primate was reluctant to enter the retrieval canister in response to the avoidance warning tone during the ten-day test. A handhold was placed in the lower part of the canister and the primate then responded to the noxious stimulus following the 10 KC tone by entering the retrieval canister; he stayed there while the 2000 cfm fan was operating.

The waste management system worked satisfactorily. NH_3 concentration was less than 0.5 mg/m^3 in contrast to an allowable concentration of 3.5 mg/m^3. Air biological contamination was less than one organism per ft^3.

The TV system operated satisfactorily throughout the test, meeting the high resolution (0.010") requirement and also providing wide angle viewing of the cage and primate using the zoom, pan and tilt functions. Some interference was evident from the screens protecting the Mylar films.

The heating system maintained cage temperature at $77^{\circ}F \pm 1^{\circ}F$ as specified, and the air circulation equipment provided the required flow rates, but with a higher noise level than desired ($\sim$ 82 dB). Replacement fans were located which would provide lower sound level ($\sim$ 75 dB) but at the cost of increased power. Delivery schedule problems prevented installation of these fans without a significant delay in test start-up at NAMI. The fans now in the TFDM represent the closest match to the flight configuration and power level which could be accomplished using "off-the-shelf" components.

The exercise device operated satisfactorily, as did the behavioral task panel.

The feeder operated without incident, as did the water system, except for microbiological contamination.

The biomedical and activity monitoring systems were demonstrated prior to the acceptance test. The magnetic activity monitor appears to be exceptionally sensitive to solenoid and switch operation. Some interference from a local radio station was picked up on the temperature channel, but this should not be a problem at NAMI. The sound detection system occasionally picks up events not related to animal vocalization.

A number of anomalies were observed in the operation of the behavioral programmer; a NASA representative was to be sent to LMSC to review these problems and assist in corrective action to be taken during the refurbishment period.

REFURBISHMENT AND SHIPPING

As a result of the 10-day and the 48-hour phases of the acceptance test, a directive from NASA was recieved which acknowledged that the TFDM had successfully completed acceptance testing. However, a list of 12 items were required to be worked off during the refurbishment period and satisfactory performance demonstrated for the on-site NASA representative. The task list is presented below:

- Determine and correct cause of ΔP switch failure during the 48 hour test.
- Replace the "calibrate" and "run" potentiometers on the mass measurement readout panel.
- Complete the installation and checkout of the animal "core temperature" readout system.
- Install the silencer and ΔP probe for the redundant 200 cfm fan.
- Determine and correct the cause of the negator failure during cage roll up and retraction.
- Demonstrate and photograph oscillograph readouts of signals for the NAMI interface equipment.
- Design and fabricate the necessary logic to have the exercise cue lights alternate "on" and "off" as a function of desired handle stroke positions.
- Demonstrate, preferably with the primate in the system, that the latch-up with the solid piston top performs properly.
- Demonstrate that the modifications to the "primate in canister" indicator operates satisfactorily.
- Calibrate and install the necessary markings on the exerciser "handle-position" meter face.
- Investigate spurious operation of the voice operated relay by apparent electronic signal transients.

- Replace the ECS exhaust ducting with fire proof or self-extinguishing ducting.

In response to this directive, the problems, causes and corrective actions taken are presented below:

Problem	Cause	Corrective Action
200 cfm fan low ΔP light failed to indicate fan shutdown	Plumbing blockage	Replumbed and checked out OK several times
Cage liner tether pull-out	Tie-down set screw not tight enough	Set screw hole re-tapped. Set screw tightened. Swaged ball attached to cable end as backup. Retrieval system operated successfully.
Retrieval piston failed to seat in retrieval canister	Piston misalignment, insufficient chamfer on latches and surfaces guiding piston to seat, and excessive O-ring hardness	Piston actuator mount re-worked to improve piston alignment with retrieval canister. Piston guiding surfaces and latches reworked to have additional chamfer. Softer O-ring installed. Piston seating was checked several times and then a successful retrieval was accomplished with a live primate
Capsule noise level higher than desired ($\sim$85 db)	200 cfm fan aerodynamic noise	A replacement fan was located which can reduce the noise level to approximately 75 db. Replacement fans cannot be procured in time for 90-day test but can be retrofitted to the TFDM. Improved sound insulation material was found which may reduce noise level but it was not suitable for use in closed atmosphere system.

Problem	Cause	Corrective Action
Spurious operation of voice-operated relay	Audio noise spikes from the air circulation system. Location of microphone in cage roof.	Corrective actions were identified as (1) noise reduction in capsule and (2) relocation of microphone to lower part of cage. These could not be accomplished in time to support the 90-day test.
Programmer anomalies	Noise spikes from motors and relays, lack of buffering in programmer and faulty "clock circuit" module in programmer.	The NASA representative and LMSC engineer diagnosed problems and added components to both suppress noise spikes and to filter remaining noise. The "clock circuit" module was replaced in the programmer, clearing up day-night cycle time error. Programmer anomalies were for the most part eliminated from the system.
"Primate in canister" signal sensitive to animal position in retrieval canister	Primate must make contact with positive and negative electrodes in canister. Some positions of primate do not provide necessary contact.	Two additional electrode rings were provided in the canister, greatly improving chance for proper contact. During subsequent animal retrieval tests, the system worked satisfactorily.

In addition to the above items, the following additions and modifications were made to the TFDM and the control console:

- The "calibrate" and "run" potentiometers on the mass measurement system were replaced with higher quality, more reliable, units.
- Installation and checkout of the animal "core temperature" readout system were accomplished.

- The silencer and ΔP probe for the redundant 200 cfm fan were installed and checked out.

- Oscillograph readouts of signals for the NAMI interface equipment were demonstrated and photographed.

- Exercise cue lights and associated circuitry were modified to alternate "on" and "off" upon reaching the handle stroke and points.

- Exerciser handle positions were permanently marked on the control console meter face in accordance with a calibration of the analog output of the exerciser position potentiometer.

- The ECS exhaust ducting was replaced with self-extinguishing material.

- The 200 cfm fans and the heaters were electrically interlocked so that fan operation is required before the heaters can be energized.

Refurbishment

After completion of the above listed items, the TFDM disassembly was started in preparation for shipment. The waste management system (See Fig. 67) was removed, cleaned, and the urine absorption material replaced and impregnated with phosphoric acid. While the waste management system was removed from the TFDM, the feces collection container was removed and cleaned. During this time the cage floor, cage liner, cage backup structure, and overall interior were cleaned thoroughly using a germicide mixture followed by a wipe-down with alcohol.

Tablets were removed from the feeder and the interior or the device cleaned. After this an operational check was made and the unit found to be satisfactory. The spare feeder was disassembled, inspected, cleaned, lubricated, reassembled and tested by dispensing 1000 tablets on motor #1 and 1000 tablets on motor #2 without incident.

The water tanks were drained and flushed with a sodium hypochlorite solution and then purged with filtered dry nitrogen. The system was then resterilized using a 90% CO_2-10% ethylene oxide mixture. The tanks were then recharged to capacity with filtered, heat-sterilized tap water. Water samples were subsequently found to be contaminated with microorganisms. An investigation into the filling procedure revealed that water backflow from the tanks had ruptured the micro-organism filter allowing entry of organisms into the system. Because of shipping schedules, a joint NASA/LMSC decision was made to ship the TFDM water system dry. The tanks were drained, flushed with sodium hypochlorite solution and the system dried with dry nitrogen.

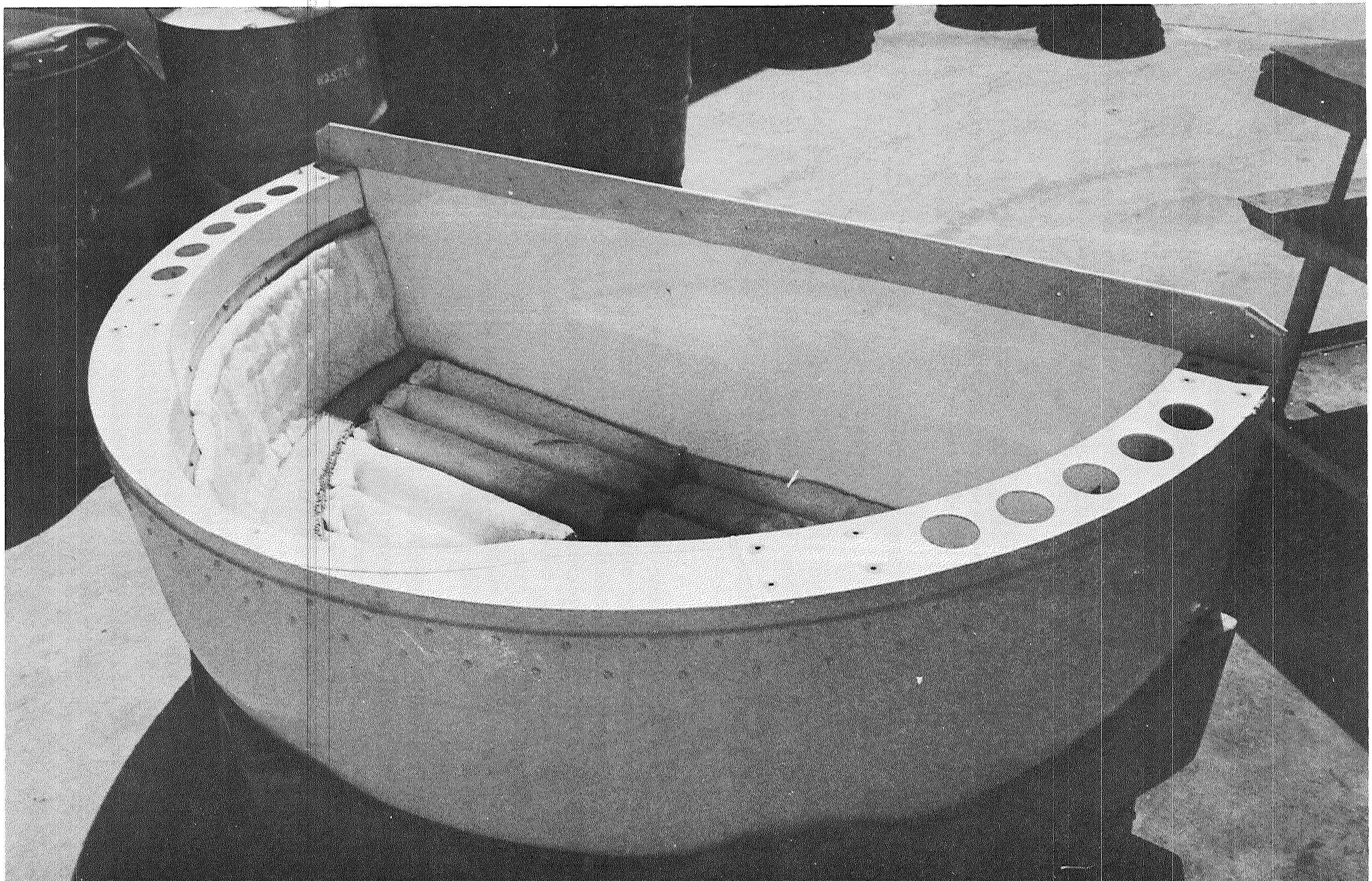


Figure 67 TFDM Waste Management System Refurbishment

Shipment

As the TFDM was disassembled, the hardware was prepared for shipment and packaged using plastic covering for all assemblies and then placing them in wooden cases.

Each item was listed on the Material Inspection and Receiving report, Form DD 250, which in turn served as a by-off document for the hardware.

The complete TFDM system, including the control console, was shipped to the Naval Aerospace Medical Institute, Pensacola, Florida, in a special air-conditioned air-ride van. Date of shipment was 28 July 1969.

TECHNICAL FEASIBILITY DEMONSTRATION TEST
NAVAL AEROSPACE MEDICAL INSTITUTE (NAMI)

The final technical feasibility demonstration test, conducted at the Naval Aerospace Medical Institute, Pensacola, Florida, was designed to prove the hardware concepts using primates for extended periods of time.

Test Preparations

Hardware installation.- The shipment arrived at NAMI on 4 August 1969. (See Figure 68). The TFDM was moved into an acoustic and RF-attenuating room, and re-assembly started. Within the first week, the basic re-assembly was completed, as shown in Figure 69. The electrical interface cabling was installed between the TFDM, the LMSC control console, and the NASA-furnished recording racks. A careful inspection of the TFDM was made to insure that the assembly was complete and correct, and that all electrical connections were verified. The TFDM and console was checked out per the countdown procedures and TFDM operation was verified to be as it was when the unit was shipped from LMSC.

A photo sensor system was added to the TFDM at the social window to record the primate's activity at this location.

Lockheed/Northrop interface.- The Lockheed and Northrop TFDM's were connected at the social window interface, using a rubber gasket between the two to prevent air or light leakage.

Both the LMSC and Northrop water systems were sterilized using a 10% ethylene oxide - 90% CO_2 gas mixture. The water systems were then charged with local tap water which had been filtered, sterilized and treated with sodium hypochlorite to achieve a free chlorine residual of approximately 0.5 ppm.

During final systems checkout, the top-mounted video camera on the Lockheed TFDM failed and was returned to the supplier's local distributor for repair.

Test Operations and Results

The primate (2Z4) entered the Lockheed capsule on Friday, 24 October 1969 for the official beginning of the Technical Feasibility Demonstration. During the first week of test, the top-mounted video camera system failed to perform satisfactorily despite the repairs by the supplier. Attempts to count and record primate vocalizations were discontinued since major noise interferences masked the vocalization events of interest. All systems essential to primate well-being (food, water, light, temperature control and air circulation) continued to operate satisfactorily throughout the test.

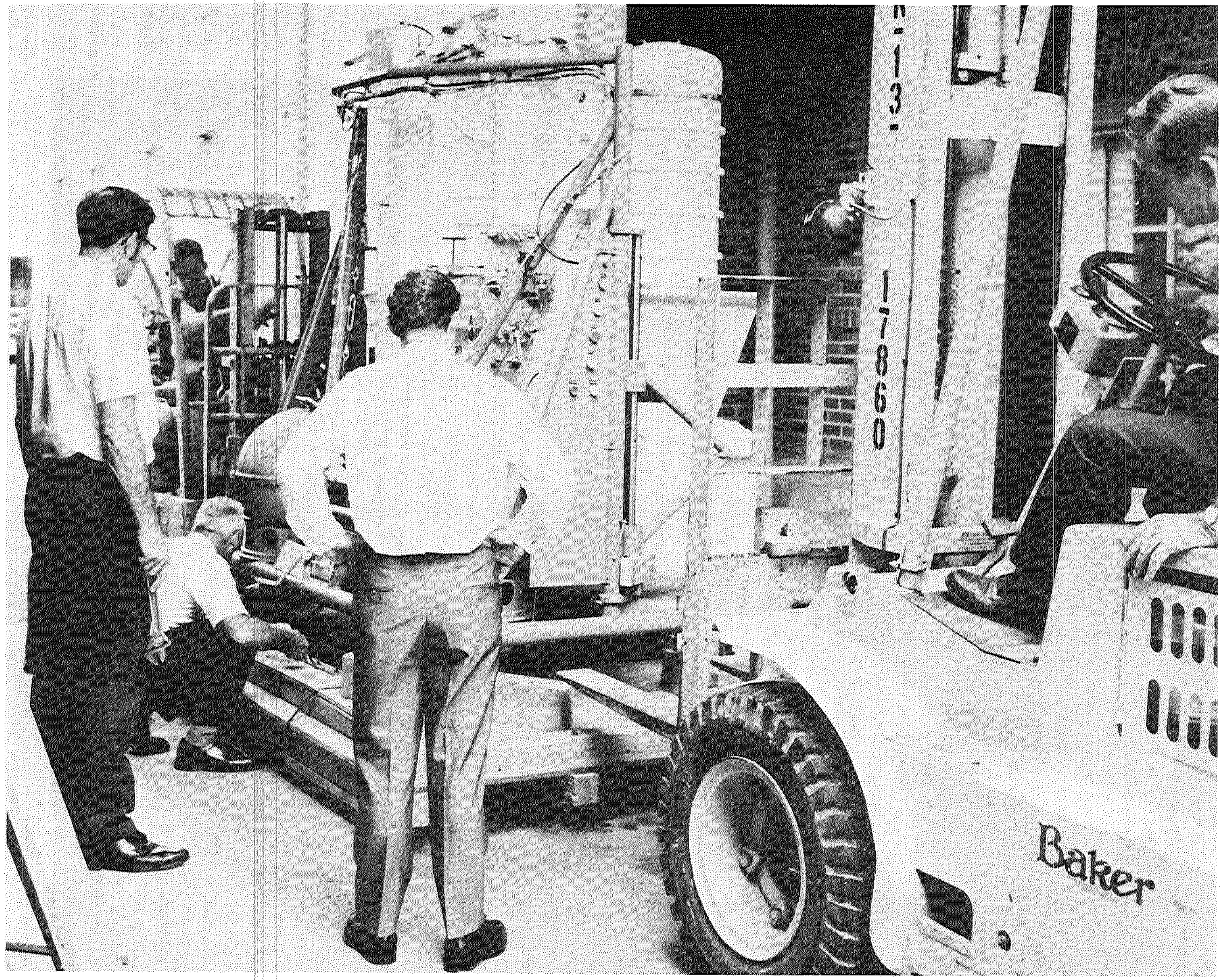


Figure 68 Uncrating of TFDM at NAMI

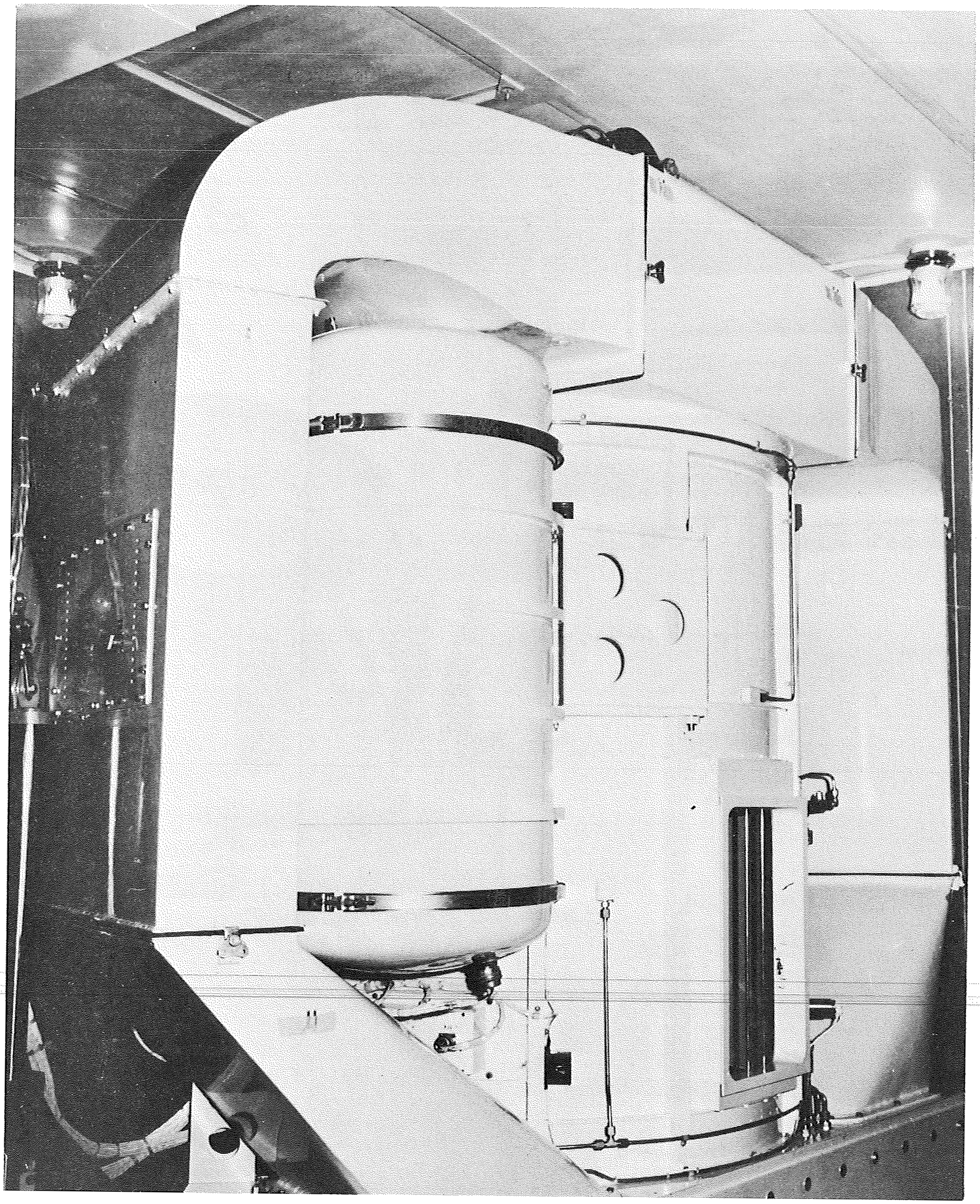


Figure 69 TFDM Installed in NAMI Test Chamber

The primate lost weight while adapting to the conditions of the behavioral regimen. The anticipated problem of weak motivating effects of water deprivation became apparent more immediately and more severely than expected. By allowing the primate to obtain water on an ad-lib basis, his weight recovered rapidly. For this reason, the requirement to work for water was deferred until the primate became better adapted to the test environment. The implanted ECG transmitter failed early in the test, but the decision was made to proceed without it due to (1) the major time requirement for re-implantation and (2) the fact that a significant amount of information could be achieved using the systems which were functioning satisfactorily. The temperature transmitter provided a signal throughout the test, however, signal dropout occurred rather frequently. With the available temperature data, a good circadian temperature cycle was apparent.

After a brief period of instability, the circadian cycle became most evident in the primate's activity. Nearly no movement was detected at night. Upon awakening, 2Z4 typically spent several minutes to nearly an hour in the retrieval canister. A work period ensued typically interrupted by a lull around mid-day. Mutual grooming seemed to be most frequent in the evenings. 2Z4 appeared to have difficulty in operating the exercise device from one extreme position to the other.

During the second week of test, 2Z4 became much better adjusted to his living conditions. A decision was made at this time to continue the test to 18 December in its current configuration, to interrupt it at that time for significant modifications, and repair, and then to resume testing for additional data gathering.

After 21 days of testing, 2Z4 had regained 100% of his original weight, and the primates' social interaction increased; they were observed arm-wrestling through the social window opening.

During the fourth week of testing, 2Z4 was able to remove the "O" ring seal from the retrieval canister. This seal would be used only under flight retrieval conditions and therefore did not effect the function of the ground-test hardware. It did, however, point out a design deficiency which will have to be corrected. Periodic difficulties were encountered during this week with the day-night illumination cycle controlled by the Northrop programmer. At this point in the test, fecal material was noted to be building up in the retrieval piston area.

In the course of color photography, an old lesion on 2Z4's foot was observed to be open; however, treatment was not indicated.

Initial oscillations in water intake which were as large as two days in duration, were damping out and 2Z4 had reached approximately 102% of his initial body weight. Both primates appeared to be even more active and generally behavior was sharper on the components of the behavioral regimen.

After five weeks of testing, 2Z4 weighed 5% more than his previous high weight. He continued to maintain such a satisfactory weight despite completing approximately 400 correct behavior sequences each day in order to earn his 300 food pellets and 100 water aliquots. At this point in the test, a great improvement was made in the primate temperature telemetry reception by the addition of a noise-rejection circuit to the receiver.

Test personnel noted that the odor from the TFDM was offensive, however, the primate does not appear to be troubled by it. During the sixth week, white noise and a continuously playing radio were introduced into the test chamber in order to mask camera noise. During this week, the accumulation of filth on much of the cage inner wall was beginning to be most noticeable. Conditions remained essentially stable from the sixth week to the end of the test.

A summary of major test results on the LMSC hardware is shown below:

1. Cage temperature remained within $\pm 1^{\circ}$F of the 77°F set point.
2. Water aliquots were checked before and after the test with the following results: 2.880 ml (before) and 2.879 ml (after).
3. Primate health after the test was good and he had gained about 5% in body weight during the test. Correlation between animal weight and mass measurement system indication: 7.365 Kg actual vs 7.4 Kg as indicated by the mass measurement system.
4. Primate major locomotion activity was primarily from the floor area to the retrieval canister and back.
5. Hair loss on the primate was less than it appeared to be via video viewing. New hair growth over surgical areas was approximately 1" long.
6. The primate did a good deal of picking and chewing on the cage and apparatus; he was able to pick out one rubber seal used in the retrieval canister.
7. The primate operated the feeding and watering lip switches almost exclusively with his mouth.
8. There was an undesirably large fecal waste buildup in the retrieval piston area.
9. The exercise unit did not appear to be consistent in regard to the operating force required and the force required is larger than desired.
10. During the test, the top viewing TV camera did not provide the quality observed prior to delivery to NAMI. This problem was recognized early in the test and a decision was made to proceed, using the combined top and side TV views for animal coverage. After the test, the entire camera system was returned to the manufacturer for complete servicing.
11. The capsule exhaust-gas odor level was objectionable to test personnel, but had no apparent effect on the primate. Inclusion of the ECS charcoal in the waste management system wicks rather than in the ECS process loop is indicated.

12. Biological tests* on the water supply using the Standard Millipore Filter Method for the identification of coliform group organisms were negative throughout the test. Blood agar plate samples were positive for growth of the following organisms on the dates indicated:

10-16-69	_Bacillus spp._
10-23-69	_Bacillus spp._
10-30-69	Unidentified gram neg. rods
11-6-69	_Staph_, _Streptomyces_ and gram neg. rod
11-14-69	_Staph_ and _Streptomyces_
11-24-69	Gram neg. rod, TNTC
12-1-69	Gram neg. rod, TNTC; Identified as _Pseudomonos spp._
12-8-69	_Pseudomonos spp._, TNTC
12-15-69	_Pseudomonos spp._, TNTC
12-18-69	_Pseudomonos spp._

*All data from Naval Air Station, Pensacola, Florida.

CONCLUSIONS & RECOMMENDATIONS

The TFDM Program proved that hardware can be designed and fabricated to satisfactorily interface with and support unrestrained primates for long durations. This can be done with existing state of the art techniques, but additional development will be required prior to producing flight designs.

Summarized below are the findings of the TFDM development and test program:

Conclusions

- The general feasibility of conducting an experiment of this nature was established.
- Significant problems exist with electromagnetic noise interference with the biotelemetry system.
- The water system becomes contaminated with a variety of organisms, probably by growth from the lip device back to the water tank. This contamination was not sufficient to cause difficulties to the animal or to the water system hardware.
- The waste management system absorbed urine satisfactorily. Some fecal waste buildup was observed in the retrieval piston area, but it did not endanger the primate or interfere with system operation.
- The ammonia concentration in the capsule was held below the allowable concentration, but the odor level in the capsule was higher than anticipated. This did not appear to affect the primate.
- Noise from the TV pan, tilt and zoom system was distracting to the animal and made it impossible to change the viewing angle and/or magnification without evoking a response from the primate.
- The cage rollup and retrieval concept was demonstrated and proved satisfactory, but a new seal design is required for the retrieval canister.
- Floor louver spacing proved satisfactory, allowing fecal material to pass into the collection container.
- The exercise unit did not appear to be consistent in regard to the operating force required and the force required is larger than desired.
- The feeder, of bulk food storage design, proved very satisfactory and reliable.
- The water system tankage, valving and aliquot accumulators proved satisfactory and reliable.
- Retrieval canister "primate in canister" sensor did not prove reliable.
- Animal vocalization system performance was below the design goal.
- Fan noise is excessive.
- Protective screens for the Mylar film system are too prominent in the TV picture.

Recommendations

- Determine the sources of noise entering the biotelemetry system at the NAMI test site. Determine at what point in the biotelemetry system the noise is entering the system, such as antenna or pre-amplifier, and isolate the noise at that point. Consider moving the biotelemetry receivers from the control console to the TFDM structure, where they would be closer to the receiving antenna.
- Consider high temperature water storage to prevent microorganism growth and/or UV treatment of water in the delivery line as close to the lip device as possible.
- Include the ECS charcoal in the waste management system wicking to reduce the odor level in the cage.
- Reduce the noise in TV pan and tilt system by the use of fiber gears and rubber shock isolation mounting of the complete assembly and the motor drive system.
- Rework the exerciser unit using ground tubes with very close tolerance control. Replace pulleys and belts with precision gears. Design special constant-force spring to counter tube mass and system friction.
- Replace existing "primate in canister" sensor with a minimum of four photo cells at various levels in the retrieval canister at 45° clocking.
- In the animal vocalization system, use a continuous running endless tape for recordings and transfer primate vocalizations to a second recorder which would operate only when required. In this way, the first sound emitted would be recorded. Reposition the pickup microphone away from the existing fans and nearer to the behavioral task panel. Lower fan background noise by using squirrel cage fans in the 200 cfm air loop. This would lower the sound level to approximately 75 dB, however, about twice the electrical power is required.

It is further recommended that the existing bulk storage feeder be either flown onboard a zero-g aircraft or be tested in the inverted position under one-g conditions to achieve greater confidence in the zero-gravity performance of this system. It is also recommended that a model of the waste management system be flown on board a zero-g aircraft for performance measurements in the zero-g environment.

The results of this program fully support the fact that the design and fabrication of hardware to support long-duration orbital testing of unrestrained primates is possible within the existing state of the art.

REFERENCES

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2. Lockheed Missiles & Space Company, Final Report, Alternate Mission Modes Analysis for Orbiting Experiment for Study of Extended Weightlessness, J. M. Smith, J. A. Dippel, et. al., NASA CR 66751, Sunnyvale, California, 20 December 1968.

3. Fields and Waves in Modern Radio, Ramo and Whinnery, Second Edition, Chapter 9, John Wiley, New York, 1953.

Appendix A

Glossary

a	Radius of cage, m
AVD	Avoidance (behavioral regime component)
c	Velocity of light, m/sec
dBm	dB relative to one milliwatt
ECG	Electrocardiogram
ECS	Environmental Control System
EMI	Electromagnetic Interference
EXC	Exercise (behavioral regime component)
ILK	Interlock (behavioral regime component)
LMSC	Lockheed Missiles & Space Company
NAMI	Naval Aerospace Medical Institute
OPE	Orbiting Primate Experiment
PAPR	Product Assurance Program Representative (LMSC designation)
Spp	Species
TE	Transverse electric mode
TFDM	Technical Feasibility Demonstration Model
TIM	Timing (behavioral regime component)
TM	Transverse magnetic mode
TNTC	Too numerous to count
VIG	Vigilance (behavioral regime component)
VOR	Voice operated relay
WAD	Work Authorizing Document
2Z4	NAMI test primate identification

ABSTRACT

This report summarizes the design, fabrication and testing of a Technical Feasibility Demonstration Model (TFDM) of a one-primate configuration of the Orbiting Primate Experiment hardware previously reported in CR-66520. The TFDM has provisions for supporting a 6 Kg rhesus monkey in an unrestrained fashion for a period of one year. Subsystems include: feeder, waterer, waste management, air circulation, temperature control, TV and illumination, behavioral programmer and associated task equipment, biotelemetry of ECG and temperature, detection of primate activity and vocalizations, primate mass measurement and automatic primate retrieval at experiment conclusion. Among the tests reported are feeder vibration (SI-B launch), accelerated one-year life testing of the feeder and waterer and acceptance tests at LMSC, and a 56-day primate test conducted at the Naval Aerospace Medical Institute, Pensacola, Florida.